ROYAL SOCIETY OF CHEMISTRY

ERC Enterprise Research Centre

What works for innovation: supporting R&D and innovation in deep tech chemistry SMEs

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Executive Summary

Whether it is tackling climate change, helping to create sustainable processes, or improving and saving lives, chemistry SMEs have a crucial role to play in developing new technologies which can transform our world. Despite the crucial role of chemistry SMEs, they are not well understood or supported in the UK. This report aims to shed some light on the challenges, barriers and unique contributions of a specific subgroup of chemistry SMEs; deep tech chemistry SMEs. We explore the characteristics of these deep tech chemistry SMEs, their potential contribution to the UK's mission-driven innovation agenda, and how we can better support these firms to maximise their innovation impact.

This study was commissioned by the Royal Society of Chemistry (RSC) before the publication of the Innovation Strategy. However, the Innovation Strategy recognises the potentially transformational role of innovation by deep tech SMEs. The central question we address is how the UK government and other support organisations can best help deep tech chemistry SMEs to maximise their R&D and innovation success and contribution to economic and social value.

Evidence gathering involved a review of existing quantitative data sets and policy approaches in the UK and internationally; interviews with 35 deep tech SMEs and industry experts and workshops with industry insiders and policy-makers. The outcome is a series of policy options to support deep tech chemistry SMEs, a number of which would also benefit deep tech firms in other science sectors.

What is a deep tech chemistry SME?

There is no universally agreed definition of deep tech chemistry. Deep tech firms are R&D active firms in which the R&D activity itself is central to the strategic approach of the firms in which success is dependent on underlying IP, novel technological advances and requires concerted R&D investment to move to market. Deep tech businesses are recognised by three attributes:

- their technologies can have a disruptive impact on markets and technologies;
- developments take a long time to reach market-ready maturity; and
- they require a substantial amount of capital.

Official datasets provide little insight into deep tech chemistry SMEs. Indeed, many smaller deep tech firms are deliberately excluded from some government sources – e.g. the UK Innovation Survey – which only covers firms with 10 employees or more.

While little insight is available from government data on deep tech chemistry firms, survey data can provide information on the broader group of chemistry SMEs. Data from the UK Innovation Survey suggests that chemistry SMEs are around twice as likely to be investing in R&D as other SMEs and also more likely to be investing in other innovation activities.

Chemistry SMEs are more likely to be engaged in new to the market innovation, with 16 percent of chemistry SMEs involved in new to market product or service innovation compared to 9 percent of all SMEs and 8 percent of Chemistry-intensive SMEs involved in new to market process innovation compared to 4 percent of other SMEs.

Understanding deep tech chemistry SMEs

The Innovation Strategy identified the difficulties which deep tech SMEs face in accessing finance, in part due to the length of time required to develop their technologies. Our research corroborates this, illustrating the complexity of deep tech chemistry firms' journeys, the decisions required and the range of factors (entrepreneurship capabilities, technology, other management skills, technical skills, finance, equipment, access to good advice, networks, collaboration opportunities and effective IP management) which need to align for success. In all of these areas the SMEs interviewed faced some barriers, and in all of these areas, there are at least some distinguishing characteristics of deep tech chemistry SMEs.

The development journey of deep tech SMEs raises many issues which challenge the ability of the entrepreneur. Good innovators do not necessarily have the skills to identify a market, value their proposition, develop a business plan which navigates the complexity of chemistry innovation, know where to go for investors and how to pitch (a difficult sell) effectively, identify useful networks and collaborators and deal with IP and regulatory regimes.

Access to finance, as recognised by the Innovation Strategy is a challenge for deep tech SMEs, but goes alongside a number of other issues which increase the risk of investing in these firms. These factors are not only evident in chemistry deep tech SMEs but perhaps heightened, with the need for, and shortages of, specialised equipment and a long and highly regulated testing process being distinguishing challenges for chemistry SMEs.

Current support for deep tech SMEs in the UK and elsewhere

The UK has a well-developed national R&D and innovation support system which offers a wide range of public support for innovating firms across the country. However, in the UK and internationally, we identified no specific measures targeted at either chemistry SMEs or more specifically deep tech SMEs.

Indeed, few countries have consistent and different policy approaches for innovative SMEs. South Korea and Italy have both implemented policy approaches with a more specific focus on innovative SMEs. In both cases there is some positive impact evidence, consistent with wider evidence of stronger policy additionality effects in smaller firms.

In our interviews with SMEs and industry experts we explored their current engagement with government institutions and policy and noted a range of challenges many of which reflected the issues highlighted earlier. Most of these issues were generic to deep tech SMEs, a number were chemistry-specific or at least impacted more intensively on deep tech chemistry SMEs.

Two challenges stand out in particular. First, within the context of the national system supporting R&D and innovation there is considerable geographical variation for chemistry SMEs seeking support from their local university and associated networks. Second, the effectiveness of the UK innovation system in supporting commercialisation has been questioned, an issue of critical importance to the success of deep tech firms in chemistry and other sciences. Limitations in the support available for commercialisation often overlap with the regional disparities.

Why support deep tech chemistry SMEs?

The case for intervention to support chemistry deep tech SMEs has two key elements: first, the potential of chemistry deep tech SMEs to introduce innovations which may have very substantial social returns and contribute to innovation missions; and second a range of market failures which are currently constraining their innovation activities.

Innovation in chemistry is fundamental to achieving potentially transformational breakthroughs in a range of areas from climate change, to developing new treatments for a number of diseases including cancer and to addressing plastic pollution. The implication is that innovation in these firms has the potential to generate very significant social, economic and environmental benefits which far exceed the direct benefits to the businesses concerned. In more technical terms, innovation in deep tech chemistry SMEs can drive very significant and positive externalities suggesting a *prima facie* case for policy intervention.

Market failures may constrain innovation and the available literature and the empirical evidence from this study suggest a number of key issues in the UK. Some of these market failures are relevant to all deep tech companies, others are more specific to distinctive aspects of deep tech chemistry SMEs. The market failures most relevant to chemistry deep tech SMEs include: failures in capital markets; failures in the market for grant funding; failures in the availability of premises and specialist equipment; information failures and perceptions of risk; failures in technical and managerial skills development.

Better supporting deep tech chemistry through Access to Capital

The recent Innovation Strategy highlighted the challenges deep tech SMEs face in accessing finance. Indeed, a majority of the deep tech chemistry-based SMEs that participated in this research reported being constrained by struggles to secure appropriate finance. Addressing these constraints is crucial to securing better outcomes for these businesses in chemistry deep tech but also other science areas:

- ***Increased proof of concept funding*** – Several respondents to this study highlighted the importance to their businesses of being able to undertake proof of concept research which is often crucial to securing further funding.
- ***Angel investment*** – Several of the respondents to this study suggested that angel investment remains difficult to access outside of the so called 'Golden Triangle'. Consideration might well be given to whether online based platforms could help to overcome these issues by reducing the information barriers to investment and allowing investors access to business profiles nationally.
- ***Equity gap*** – Both the academic literature and the responses to this study confirm the existence and significance of an equity gap which means that deep tech chemistry SMEs often struggle to secure intermediate levels of funding to enable scale up and the commercialisation of new technologies. Our research suggests there is a quantitative shortage of available equity investment, and interviewees perceived a lack of scientific understanding and expertise among potential investors.
- ***Grant application processes*** – there is a strong case for evaluating whether current processes are fit for purpose in supporting deep tech innovation, and to revise these processes as appropriate. Our research identified a number of specific issues on both the supply and demand side which are constraining deep tech chemistry SMEs' access to public funding.

Better supporting deep tech chemistry through access to flexible and affordable chemistry facilities

Given the very widespread perception that the lack of availability of suitably equipped premises is a key constraint on business development and scaling up for deep tech chemistry SMEs, this is clearly an area where intervention would be both practical and useful. Existing sources of information do not appear to be well known or used by deep tech SMEs and better signposting to existing information sources may be useful. Developing new public/private partnerships for provision may also be useful here. Other policy options under this general heading are:

- ***Consider gaps in the provision of bespoke incubators/accelerators*** – The facilities provided by incubators and accelerators are clearly helpful in providing appropriate, suitably equipped, premises. Given the particular challenges our interviewees identified which are faced by chemistry deep tech SMEs in accessing suitable premises for scaling, an audit to establish what premises are available (for example in established Catapults) would be sensible. Improving the information available to firms about the facilities which are available would also be potentially beneficial.
- ***Improving access to equipment to allow scale-up*** – our interviewees stressed the difficulty of funding specialist equipment purchases particularly during the scale-up phase. Consideration could be given to whether public-private partnership investment could help with the acquisition of specialist facilities/equipment for leasing to SMEs working in chemistry deep tech.

Better supporting deep tech chemistry through better developed Innovation Management and Leadership

Perhaps surprisingly our interviews did not suggest any consistent issues around accessing technical skills. Instead, they emphasised the critical impacts on business performance associated with underdeveloped entrepreneurial and innovation management and leadership skills which were widely reported to be a common and significant constraint to business performance. Among the specific measures of most importance for deep tech chemistry SMEs are:

- ***Promoting engagement with management and leadership training***. There was a widespread acceptance amongst the SMEs involved in this research that initiatives that aim to develop entrepreneurial, innovation management and leadership skills are necessary and would be useful.
- ***Developing collaborative innovation capabilities*** – effective collaboration plays a critical role in many deep tech firms' innovation. There is a strong case for developing these managerial capabilities to support collaboration as part of any management and leadership development programme.
- ***Incentivising engagement with formal training*** – Given these concerns, one option would be to modify grant application scoring so that applicants who had completed suitable training received a small premium to the scoring of their application.
- ***Encourage the provision of business modules in post graduate training programmes*** – Respondents to this study were also concerned that post-doctoral candidates looking to work in this sector almost invariably lack any real understanding of the issues faced by these businesses. Accordingly, it would be sensible to review and evaluate the opportunities currently available for post-graduates to develop their entrepreneurial skills while at their university. Consideration might also be given to a funded internship scheme through which chemistry post-graduates and subsequently their employers would benefit from the experience and enhanced understanding of the issues involved in working in deep tech-based SMEs.
- ***Provide better IP and regulatory advice and support*** – There is a perceived need for sector specific IP guidance that considers the complexities of chemistry innovation. Accordingly, there would be clear merit in securing more widespread HEI engagement with best practice in addressing IP and associated licensing issues.

Better supporting deep tech chemistry through ecosystem and resources/networking

The businesses interviewed in this study highlighted several areas where new policy measures could contribute to the development of an enabling ecosystem more conducive to business success.

- ***Reducing spatial inequalities*** – There is no doubt that it is easier for deep tech chemistry-based SMEs to operate successfully in the Golden Triangle and London than it is for them to do so in other areas of the country. Accordingly, there would appear to be clear merit in looking to develop existing regional incubators into more substantial entities capable of comprehensively supporting businesses throughout their journeys from establishment to maturity.
- ***Establish and support networking*** – it is generally accepted that networking with peers expands the ambition, skills and confidence of SME owners and managers. Most respondents interviewed for this study agreed with this and were open to participating in peer-to-peer networking and events. While promoting networking may appear to be a 'soft' option not directly linked the challenges concerned, the evidence suggests that it would be relatively inexpensive to deliver and may well be amongst the most effective policy options available to promote growth and innovation in deep tech chemistry SMEs.

Section 1: Chemistry and chemistry SMEs

1.1 Introduction

Small and medium enterprises (SMEs) are the bedrock of economies and in the UK they account for 99 percent of all firms. SMEs also provide three fifths of the employment and around half of the turnover of the UK private sector[1]. In addition to their contribution to job creation and prosperity, some SMEs such as chemistry SMEs have another important role to play. Whether it is tackling climate change, helping to create sustainable processes, or improving and saving lives, chemistry SMEs have a crucial role in developing new technologies which can transform our world.

Box 1.1: Examples of R&D active chemistry SMEs[2]

Mimica is creating the next generation of food expiry labelling that reduces food waste and improves food safety. In the UK, 7 million tonnes of food and drink are thrown away annually, costing the average UK household £470 a year. Mimica Touch is designed to tell if food is still fresh, so more money could be saved, and less waste created.

Sygnature Discovery is a world-leading integrated drug discovery and non-clinical solutions provider, offering expertise across a broad range of therapeutic areas and biological target classes. Sygnature Discovery supports the R&D and innovation of organisations such as pharma companies, biotech start-ups and universities. Since 2011 they have contributed to 34 drug candidates, 17 of which are already in clinical trials.

Reading Scientific Services Ltd (RSSL) provide research, analysis and consultancy to the food, life science and consumer goods sectors, partnering with both SMEs and all the top 15 global pharmaceutical and FMCG companies. RSSL are helping over 3,000 clients from across 60 countries create new products, validating medicines or solving difficult technical challenges.

Exscientia is an AI-driven pharma-tech company committed to discovering and designing the best possible medicines in the fastest and most effective manner. Exscientia is the first company to progress AI-designed small molecules into the clinical setting and have repeatedly demonstrated the ability of AI to transform how drugs are created. Exscientia's AI platform has now designed two drugs that are in Phase 1 human clinical trials.

Bitrez is a leading manufacturer of specialist polymers and chemicals. Using creative chemistry Bitrez develops innovative products that resolve regulatory and technical problems. With new developments in sustainable feedstocks that do not impact the food chain or contribute to deforestation, Bitrez is developing more bio-based products that enable the formulation of specialist coatings, adhesives, and matrix systems for the protection, fixture, or manufacture of components.

Despite the crucial role of chemistry SMEs, they are not well understood or supported in the UK. It is often believed that chemistry SMEs are all very similar, when the reality could not be more different. Box 1.1 highlights only a few examples chemistry SMEs, which are R&D active. Chemistry SMEs are a widely diverse group of firms spanning a wide range of industries from agrochemicals to cosmetics, pharmaceuticals to energy. Chemistry SMEs also vary in the roles they play in supply chains and business eco-systems. Types of firms include contract research organisations, analytical services, manufacturers, chemical distributors, consultants and other R&D active firms, amongst others. Many of these firms are innovative and actively contributing to the development of solutions that enable a better future for people and planet.

This report sheds some light into the challenges, barriers and unique contributions of a specific subgroup of chemistry SMEs - deep tech chemistry SMEs. We explore the characteristics of these deep tech chemistry SMEs, their potential contributions to the UK's mission-driven innovation agenda, and how we can better support these firms to maximise their innovation impact.

1 See https://www.gov.uk/government/statistics/business-population-estimates-2020/business-population-estimates-for-the-uk-and-regions-2020-statistical-release-html#composition-of-the-2020-business-population, Figure 2.

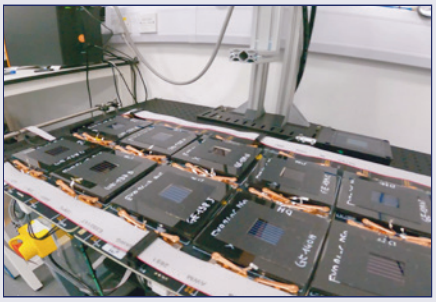
2 Overviews derived from business websites all accessed 21.12.2021. Sources: Mimica (mimicalab.com); About Us And What We Do For Drug Discovery | Sygnature Discovery; Working with Us - Sygnature Discovery; Reading Scientific Services Ltd | RSSL; Exscientia | AI Drug Discovery | Pharmatech; Industries – Bitrez Polymers and Chemicals.

Box 1.2 Examples of deep tech chemistry SMEs and their potential impact

Carbon capture – creating value from carbon dioxide

ViridiCO$_2$ Ltd incorporated in December 2020 and spun-out intellectual property in November 2021
Their technology, known as Carbon Capture Utilisation (CCU), transforms high volume waste carbon dioxide gas emissions from established chemical manufacturers and foundation industries such as steel and cement into high value carbon-based chemicals and feedstocks which can be found in everyday items such as furniture or batteries. Chemical and Foundation industries are responsible for ~16% of global greenhouse gas emissions of which 80% are carbon dioxide (CO_2), which equates to 8 billion tonnes every single year. Creating these new polymers from waste CO_2 also removes the reliance on fossil fuels at the same time as helping the environment, thus advancing UK chemical manufacturing processes. This innovative approach has been shown to save time, money and energy, the result of which contributes to a reduced carbon footprint and sustainable circular economy.

Advanced solar cells – converting more energy from the sun



Oxford PV was spun out of the University of Oxford in 2010 and has since grown to be a company of approximately 130 employees combined at its sites in Oxford and Germany. It has developed perovskite, a new affordable solar cell material that can convert significantly more energy from sunlight, this in turn supports net zero ambitions, an example of which being greener buildings.

Existing silicon-based solar cells can only convert 15-10% of sunlight into electricity and have already reached their maximum practical theoretical efficiency limit of ~26%.

Oxford PV's perovskite technology has been designed for use with conventional silicon cells to break through the efficiency ceiling. The technology has already set world records for solar efficiency, currently at >29% and the company is confident this figure can be improved. The material will help solar become more affordable by delivering 20-50% more power using the same surface area. This is critical in accelerating adoption of clean solar energy, making it more accessible to both households and businesses alike.

The company expects to start commercial production of these solar cells by the end of 2022.

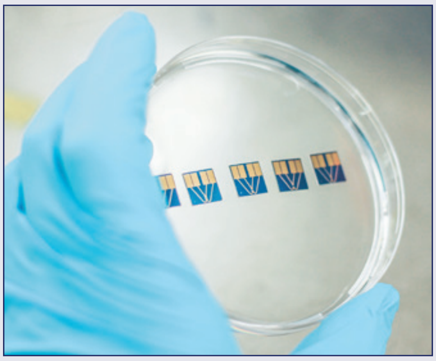
Superfast charging – next generation battery technology

Echion Technologies is a world-leading developer of advanced lithium-ion battery materials. They have developed a product that only requires a 6-minute charge, which is inherently safe compared to present systems and these batteries have a 10-fold increased lifetime over that of a standard Lithium-ion cell.

Their products therefore contribute to the ambitions for zero emission vehicles: they enable cell manufacturers to deliver cost-effective, fast-charging, high-energy density, and long-life power cells. These will supply end applications for a wide range of markets where downtime equals significant cost such as taxis, forklift trucks, industrial EVs or those requiring high safety, high power and a long lifetime such as railways, ferries or grid systems. Many high usage applications need to have spare vehicles as they simply cannot afford the downtime associated with present slow charging battery technology. Having secured non diluting grant funding via Innovate UK in the early years to develop the components, they have since attracted private equity investment of nearly £12 million, further validating their global potential.

The team is now expanding by over 50% to recruit engineers, scientists and senior leaders.

Graphene sensors – portable analysis tools for cheaper, faster drug development

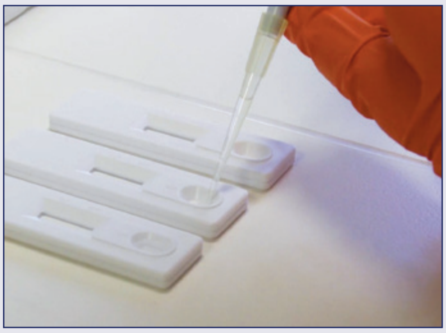


HexagonFab, a fast-growing biotech company has developed Bolt, a portable analysis tool containing a graphene composite sensor which will accelerate drug research and manufacturing.

A recent London School of Economics and Political Sciences study found the average cost of drug development was $1.3 billion and sector data has shown that only 1 or 2 out of every 10,000 drug candidates will become a marketable medicine. Considering that globally 75% of new drugs are being developed by SMEs, this new instrument will enable faster and cheaper drug discovery which will be more accessible to SMEs. Bolt will be a step change, replacing current methods that are outdated, complicated, expensive and slow. It will reduce the cost of assessing the efficacy of potential drug candidates tenfold and reduce the time taken from days to hours.

HexagonFab's platform technology has potential applications in diagnostics and industrial monitoring. Not only will their technology lead to new treatments and diagnostics but also the successful large-scale manufacture of this nanomaterial will pave the way for an entire generation of new technologies.

Novel diagnostics and therapeutics – next generation testing and treatments for pandemic preparedness and combatting disease



The Covid-19 pandemic has highlighted the importance of viral and bacterial surveillance, and **Iceni Glycoscience's** novel technology could be critical in the response to future disease outbreaks.

Spun out of the University of East Anglia and the John Innes Centre in 2014, this innovative company is developing diagnostic technologies and treatments for infectious diseases using proprietary technology based on carbohydrate chemistry.

Iceni Glycoscience's technology exploits the presence of carbohydrates found on the surface of cells within our bodies where the initial binding stage of a virus occurs, enabling early detection and discrimination between different diseases in a single test. Existing tests rely on detecting genetic material or surface proteins and can be rendered ineffective when a virus mutates. However, by using carbohydrate-based techniques, Iceni Glycoscience has developed rapid "mutation proof" tests which can identify and distinguish between diseases, including COVID-19 and influenza.

Recent developments have recognised the importance of carbohydrates in human and animal disease, including cancer, and highlighted opportunities for developing novel treatments. In addition to diagnostics, Iceni Glycoscience is also developing carbohydrate-based therapeutics such as novel vaccines which can be used as an alternative to antibiotics.

Iceni Glycoscience's technology demonstrates the importance of innovation and is a fantastic example of how chemistry contributes to Government Healthcare mission 2 – enabling early diagnosis and treatments.

Saving lives through early detection of disease and precision medicine

Owlstone Medical have set out to save 100,000 lives and $1.5B in healthcare costs. They have developed Breath Biopsy® OMNI, an end-to-end optimised service for consistent breath collection and analysis, that aims to enable non-invasive early detection of disease and monitoring of treatment response for diseases such as cancer, liver disease, respiratory diseases and many more.

1 in 2 people will get cancer in their lifetime. Early detection is key, it increases survival chances 10-fold and reduces the cost of treatment very significantly. By 2028, the NHS cancer strategy aims to have 55,000 more people each year survive their cancer for five years or more and to provide at least 75% of people with an early diagnosis (during stage one or two of cancer).

The numbers are staggering taking into account chronic respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD), which affect over 500M people worldwide. The annual cost of treatment in the US alone is almost $60B. COPD is the third leading cause of death worldwide. Owlstone's approach aims to bring diagnostic tools into GP surgeries, clinics, and pharmacies, giving patients quicker and easier access to tests. Without novel diagnostic technologies like these, many will sadly continue to lose their lives.

Owlstone Medical is an excellent example of a chemistry technology in one sector that has led to solutions to global problems in another. Their initial focus was on applications in the defence sector. After Owlstone's CEO's wife lost her battle with cancer, following a late diagnosis, they concentrated efforts on medical applications. Owlstone Medical was formed in 2016. In the last few years, they have more than doubled in size, now employing around 200 staff.

Underlying our analysis is the view that government policy and other support organisations can make a critical contribution to the success or failure of scientific research and innovation, through a range of interventions, from the funding of research at UK universities to taxation policies which favour R&D investment to wider policy on international trade and domestic employment and skills. The current government's approach to supporting UK innovation was laid out in July 2021 in the Innovation Strategy. This sets out the government's vision for making the UK a global hub for innovation by 2035 and the actions to bring this about, categorised under four pillars:

- Unleashing Business
- People
- Institutions & Places
- Missions & Technologies

The Innovation Strategy presents polices and initiatives which both seek to address existing barriers in the innovation landscape and to galvanise resources to proactively address critical challenges such as the need to achieve environmental goals and, building on the success of the Covid-19 Vaccination Taskforce, to address other immediate problems as they arise. Chemistry innovation has a critical role to play in supporting the delivery of the vision articulated in the Innovation Strategy. In developing these innovations, the journey from initial chemical discovery to these societal impacts is risky, capital intensive and often long (up to 15-20 years). As a result, deep tech chemistry SMEs, often rely heavily on external support either from the Government or the wider ecosystem in developing a technology from discovery to marketable proposition.

This study was commissioned by the Royal Society of Chemistry (RSC) before the publication of the Innovation Strategy. However, the timing allows for lessons to be drawn on how deep tech chemistry SMEs can be supported to optimise their innovation outcomes and contribute to the innovation missions outlined in the Innovation Strategy. The aim of our study is to enhance the evidence base associated with deep tech SMEs developing technologies founded in chemistry. The priority for the study is to understand better the needs and potential interventions required to support these deep tech chemistry SMEs, and more specifically firms in the 'establishing' phase which have not yet fully commercialised their technology. The central question we address is how the UK government and other support organisations can best help these establishing firms to maximise their R&D and innovation success and contribution to economic and social value.

1.2 Our approach

Evidence gathering was divided into three Phases with a view to establishing a rationale for policy support for chemistry SMEs, identifying the objectives of such support measures and conducting an initial appraisal of policy options in partnership with a group of chemistry SMEs and industry experts. In Phase 1 we examined existing data sources to describe and understand chemistry SMEs and conducted a literature review to describe the wider context of innovation in SMEs and current UK and international policy. In Phase 2 we conducted new primary research with deep tech chemistry SMEs and other ecosystem players, allowing a testing and deeper exploration of the issues identified in Phase 1 and the identification of policy options. Phase 3 of the project involved testing the policy options developed with a wider group of industry and policy stakeholders.

Phase 1 of the study was conducted in Spring 2021 and focused on defining, profiling and understanding the policy and operational context of chemistry SMEs and deep tech chemistry SMEs in the UK. Defining the population of firms of interest proved complex given that there is little consistency in definitions across studies (e.g. 'R&D active', 'deep tech') and the associated difficulties in translation of definitions into a coding which would allow analysis of existing data sources. A key challenge was the extent to which it is possible to identify 'R&D active' or 'deep tech' chemistry SMEs and their R&D and innovation characteristics in existing publicly available and proprietary databases.

In particular, information on individual small firms' investment in R&D is not readily identifiable from any publicly available data source. For larger firms this data is often observable from company accounts but the restrictions of the Companies Acts mean that smaller firms are only required to publish very limited accounting data. However, while investment data on R&D may not be available for these firms, either the business description of activities available on databases such as FAME or business websites can provide a qualitative indication of firms' engagement with R&D activity. Additionally, other sources provide some data on the input measures (such as the conduct of R&D), but there are other limitations. For example, the UK Innovation Survey, the key data source on innovation activity in UK firms, excludes micro-businesses with fewer than 10 employees from the survey. This survey does however provide size and sector data and can be used for profiling the group of chemistry SMEs and addressing questions as to whether such firms are more or less innovative than other companies. The UK Innovation Survey also provides some information on whether R&D active firms are faster or slower growing or have higher productivity. We report this data analysis in Section 3, shedding some light on chemistry SMEs.

To identify the population of deep tech chemistry SMEs, it is necessary to consider the nature, development journey and potential impact of their technologies. National datasets do not provide the technology specific data required to identify these deep tech businesses and, in many cases, do not capture businesses in the micro stage of development. The definition, and how we arrived at it, is set out in Section 2. Once agreed, the definition allowed us to Identify firms and variables of interest in data sources and to develop search terms for the literature review.

The Phase 1 literature review supplemented the quantitative analysis by exploring:

- Patterns and trends in R&D activity generally, R&D activity in SMEs and in chemical sciences sectors
- Current government science and innovation policy as it relates to SMEs and the chemical sciences sector.

Finally, in Phase 1, interviews were conducted with 6 'key informants' from a variety of sector representative bodies. Phase 1 resulted in a profile of chemistry SMEs (Section 4) and an initial assessment of the adequacy of existing policy support (Section 5).

In Phase 2, we conducted new primary research based on 29 interviews with SMEs and sector experts covering climatetech, platform chemtech, medtech, and biotech. Interviews were undertaken during July and August 2021 spanning the publication of the UK Innovation Strategy which was an item of discussion in some later interviews. This gives a total of 35 interviews across phases 1 and 2. The SMEs interviewed were selected to provide a mix of establishing and established SMEs – i.e. pre or post revenue (see definitions in Section 3). All the firms interviewed were operational, with some success in either attracting private and/or public investment and a number had progressed to have products on the market. The intention was to learn from successful SMEs to identify challenges and enablers on their development journeys. While most had spun out of universities there were some non-university start-ups and whilst there was a variety of routes to commercialisation, few had sold or licensed IP outright to a larger entity.

To capture a wider range of perspectives, we also interviewed nine other stakeholders representing other elements of the support and policy eco-system for deep tech firms. These individuals included investors, advisors, larger companies and academics engaged in providing facilities for developing chemistry firms. Together, these individuals provided a broader perspective than the SMEs but also all represented their particular organisations and expertise.

Phase 3 of the project comprised a policy workshop (October 2021), hosted by the Royal Society of Chemistry, and attended by a number of interviewees from Phase 2 research (including SMEs and sector experts) and additional policy experts. This allowed us to share insights and explore the most effective policy options. Policy options emerging from our own research were also compared to those of other recent reports to identify interventions which may have benefits beyond chemistry SMEs.

1.3 Report Structure

The findings of this study are set out in this report. Section 2 defines deep tech chemistry SMEs and their potential role in meeting the objectives set out in the Innovation Strategy. Section 3 profiles SMEs which engage in research and development (R&D) – R&D-active SMEs - and identifies characteristics of chemistry R&D as far as is possible through existing quantitative data sources. Section 4 sets out the findings of our new primary research, including the development journeys of deep tech chemistry SMEs and factors which have helped or hindered their development. We then consider the UK policy environment, particularly in the light of the Innovation Strategy, and we draw in learning from international policy to assess how policy might best enable deep tech chemistry SMEs to contribute (Section 5). Section 6 presents our conclusions and recommendations for policy development.

Section 2: Defining deep tech chemistry SMEs

2.1 Introduction

As described above, a unique challenge for this study was to define and identify deep tech chemistry SMEs. There are several definitions of all the concepts involved, and where there are standard international definitions, they do not ideally or simply correspond to the firms of interest to this study. This poses significant challenges in recognising and understanding these firms, how they operate, what they need to enable them to reach their full potential as they may fall below the radar of existing data sources (e.g., the UK Innovation Survey).

In this section we first describe standard definitions of 'SME', 'R&D active', 'innovation active' and 'deep tech' and then set out how they have been utilised and interpreted in this study.

2.2 What is an SME and a chemistry SME?

In the UK, SMEs are normally defined simply by the size of their workforce. Businesses with zero to 249 employees are normally categorised as SMEs. Businesses with no employees – sole traders – are the most common category. Those with one to nine employees are categorised as 'micro' businesses, those with 10 to 49 employees as 'small' businesses and those with 50 to 249 employees as 'medium' sized businesses.

SMEs which draw on or use the products of chemistry occur in almost all sectors. Internal research undertaken by the RSC, however, suggests that firms whose main products or services are based on chemistry, and which are likely to be undertaking chemistry R&D, are concentrated in 87 industries defined by their 4-digit SIC codes. This is around a quarter of all such industry codes. In later sections we use these sectors to profile innovation activity in chemistry SMEs.

2.3 What is an R&D-active SME?

Internationally, there have been significant efforts to calibrate and define notions of 'R&D-active' and 'innovation-active' firms. Central to this has been the work of the Organisation of Economic Cooperation and Development (OECD) which developed the Frascati Manual (OECD, 2015), which defines R&D, and the Oslo Manual (OECD/Eurostat, 2018), which focuses on innovation. Using the Frascati Manual definition, UK R&D spending at around 1.7 percent of GDP is significantly below that of many of our leading international competitors. We explore this issue further in Section 3.3.

In terms of innovation, the Oslo Manual (OECD/Eurostat, 2018) is the international reference guide for collecting data on business innovation. Definitions from the Oslo Manual underpin the UK Innovation Survey and other related surveys internationally, allowing international and other comparisons of levels of innovative activity. Generally, SMEs are less likely to engage in innovation than larger businesses. The UK Innovation Survey (2019) reports that in 2016-18, 50 percent of all firms employing over 250 employees were innovation active, compared to 37 percent of all SMEs (employing 10-249 staff).

Drawing on these international definitions – and prior work undertaken by the RSC - we adopt a working definition of a chemistry SME as:

- having between 1-249 employees
- operating in a chemistry related sector (as an approximation for firms in which the products or services provided are founded on chemistry, based on a group of 87 4-digit SIC codes identified by the Royal Society of Chemistry as including chemistry companies)

2.4 What is a deep tech SME?

Deep tech firms are a sub-group of the R&D-active firms in which the R&D activity itself is central to the strategic approach of the firms and success is dependent on underlying IP, novel technological advances and requires concerted R&D investment to move to market. International definitions capture R&D active businesses within which deep tech businesses are a (small) sub-set. Deep tech businesses are recognised by three attributes:

- their technologies can have a disruptive impact on markets and technologies;
- developments take a long time to reach market-ready maturity; and,
- they require a substantial amount of capital.

These businesses develop technologies which:

- are novel and significant technological advances;
- may have the power to create their own markets or disrupt existing industries;
- require concerted R&D to develop practical business or consumer applications and bring them from the lab to the market;
- may help to address big societal and environmental challenges;
- are based on underlying chemistry IP, skills or methods, which are a barrier to entry for other businesses.

2.5 What is an establishing vs established chemistry SME?

One final definition required for the study was to identify those firms still at an early stage of development. The journey for deep tech SMEs from initial chemistry discovery to the market introduction of products and subsequent impacts can be long with some technologies requiring as much as 15 to 20 years to reach the market. Therefore, a simple 'age of firm' definition would not suffice.

For the purposes of this study, we therefore draw a distinction between establishing and established SMEs in the following way

- Established SME - an SME, which has already commercialised its technology and will have reached its operational size or is effectively scaling.
- Establishing SME - an SME, which is developing its core technology which has not yet reached the market and may therefore be pre-revenue.

2.6 Summary

SMEs with 1 to 249 employees play a critical role in the UK economy both in terms of providing employment and as the drivers of much innovation in chemistry and other sectors. While the definitions of SMEs themselves are uncontentious, our focus here is on the sub-groups of chemistry SMEs and, more specifically, deep tech chemistry SMEs. Defining these sub-groups of firms is less straightforward and standard international definitions of R&D active or innovation active firms are not particularly helpful. Our working definition for chemistry SMEs focuses on sectors identified in prior RSC research as including most chemistry-intensive companies. Our deep tech working definition recognises the centrality of chemical sciences to the success of these firms as well as their potential contribution to new innovation and resource requirements. In subsequent sections we focus on these groups of firms.

Section 3: Profiling R&D-active chemistry SMEs

3.1 Introduction

Reflecting the definitions developed in Section 2, and the limitations of the secondary datasets, this section applies the definition of chemistry SMEs based on sector and size band criteria to the UK Innovation Survey. Specifically, we use data from the UK Innovation Survey 2019 to profile SMEs (those firms with 10-249 employees) in 87 4-digit SIC codes identified by the RSC as including chemistry SMEs. It is important to note, however, that as the UK Innovation Survey only covers firms with 10 or more employees, this analysis may exclude many spin-out businesses and newer chemistry SMEs below the employee size cut-off. Despite this limitation, the UK Innovation Survey still provides the most useful source to understand the characteristics of chemistry SMEs compared to other SMEs.

In this section (3.4), we also review evidence from other phases of the research which helps us to understand the nature of chemistry SMEs and if and how they differ to other R&D active SMEs.

3.2 Investing in R&D and innovation – survey evidence

The main source of innovation data in the UK is the biennial UK Innovation Survey which is undertaken by BEIS. The survey uses definitions of innovation based on the OECD Oslo Manual and focuses on firms' innovation activities during the previous three years. The UK Innovation Survey is a sample survey, and in 2019 – the most recent data currently available - included 10,700 SMEs of which around 2,100 are in the chemistry-intensive sectors identified by the RSC and 8,600 in other sectors.

Using data from the UK Innovation Survey 2019, Table 3.1 provides a profile of firms' investments in innovation contrasting SMEs in the chemistry-intensive sectors with SMEs in the remaining sectors. Table 3.1 suggests that SMEs in the chemistry-intensive sectors are around twice as likely as firms in other sectors to be investing in R&D and more likely to be investing in all other aspects of innovation – e.g., training and acquisition of machinery – than all SMEs.

Higher levels of investment in innovation are reflected in higher levels of innovative activity in the chemistry-intensive sectors than in other sectors (Table 3.2). In particular, levels of innovation activity and product or service innovation are nearly twice as high in the chemistry-intensive sectors. More radical, new to the market, innovation is also notably more common in these sectors, although there is less of a gap in process innovation (Table 3.2).

Table 3.1: Investing in innovation: SMEs in chemistry-intensive sectors and other SMEs(proportion of firms investing)

Innovation investment (% firms)	SMEs in chemistry-intensive sectors N=2141	All SMEs N=10722
R&D	39	20
Internal R&D	38	20
Acquisition of advanced machinery	27	22
Training for innovative activities	21	13
All forms of design	18	12
Acquisition of R&D (extra-mural R&D)	10	6
Market introduction of innovations	7	4
Acquisition of existing knowledge	6	3

Table 3.2: Undertaking innovation: SMEs in chemistry-intensive sectors and other SMEs (proportion of SMEs)

Innovation behaviour (% firms)	SMEs in chemistry-intensive sectors N=2141	All SMEs N=10722
Innovation active	58	44
Product or service innovation	30	21
New-to-market product or service innovation	16	9
Process innovation	20	15
New-to-industry process innovation	8	4
Abandoned innovation activities	4	2
Scaled-back innovation activities	5	3
Ongoing innovation activities	25	13

Chemistry SMEs emerge as having higher levels of innovation investment than the SME population as a whole and significantly higher levels of innovative outputs. This applies to both incremental and more radical, novel innovations, suggesting the central role of innovation in driving the competitiveness of chemistry SMEs. Another key aspect of chemistry SMEs' innovative activity is the much greater extent of collaboration which they undertake compared to other SMEs (Table 3.3). Chemistry SMEs are more likely to be collaborating with all types of partners identified in the UK Innovation Survey (Table 3.3). The difference in levels of collaboration between chemistry and other SMEs is particularly large in the case of collaboration with universities: 15 percent of SMEs in chemistry-intensive sectors were collaborating with universities compared to only 6 percent of all SMEs (Table 3.3).

Table 3.3: Collaboration for innovation: SMEs in chemistry-intensive sectors and other SMEs (proportion of firms)

Collaboration for innovation (% firms)	SMEs in chemistry-intensive sectors N=2141	All SMEs N=10722
Suppliers of equipment, materials, services or software	21	15
Clients or customers from the private sector	21	14
Other businesses within the enterprise group	16	10
Consultants or commercial labs etc.	16	8
Universities or other higher education institutes	15	6
Clients or customers from the public sector	13	8
Other businesses outside the enterprise group	12	8
Competitors or other businesses in the industry	10	8
Government or public research institutes	9	5
Non-profit organisations	7	4

3.3 Barriers to innovation – survey evidence

Another useful indicator included in the UK Innovation Survey relates to the barriers which firms perceive to undertaking innovation. Table 3.4 shows the proportion of SMEs which reported barriers to innovation to be either 'very important' or 'important'. Chemistry SMEs rated each barrier as more significant than all SMEs. This may reflect chemistry SMEs' stronger engagement with innovation and therefore their greater likelihood of encountering these barriers. Nonetheless the relative importance of each barrier on innovation activity provides an indication of the strength of each factor in constraining innovation activity.

The costs and risks of undertaking innovation were the most commonly cited barriers to innovation among chemistry SMEs along with a lack of qualified personnel (Table 3.4). These were closely followed by the cost and availability of finance, a theme we return to in later sections of this report. The outcome of the Brexit referendum was cited as a barrier to innovation by around a quarter of chemistry SMEs at the time of the survey (2019).

Table 3.4: Barriers to innovation: SMEs in chemistry-intensive sectors and other SMEs (percentage of firms)

	SMEs in chemistry-intensive sectors N=2141	All SMEs N=10722
Direct costs too high	34	25
Lack of qualified personnel	31	23
Excessive economic risks	28	22
Cost of finance	28	23
Availability of finance	27	22
Uncertain demand for goods and services	27	20
Outcome of EU referendum	24	20
Market dominated by established businesses	22	17
UK government regulations	22	18
Lack of information on markets	20	14
EU regulations	20	15
Lack of information on technology	18	15

3.4 Understanding firms' development path – interview evidence

The evidence from the UK Innovation Survey suggests the more innovation intensive nature of chemistry SMEs compared to SMEs in general. Chemistry SMEs are investing more heavily in innovation through R&D, equipment and intangibles, they are collaborating more intensively as part of their innovation activity and have higher levels of innovation activity than other SMEs. This data is consistent with previous research by the RSC which identified several factors which differentiate chemistry-based firms, including the challenge of identifying the right market from the many potential applications of a chemistry technology; the length of time taken to reach market; and that Intellectual Property (IP) is more important than usual in chemistry SMEs[3]. The UK Innovation Survey also emphasises the more intensive barriers which chemistry SMEs face in undertaking innovation. This echoes earlier RSC studies which have highlighted funding challenges associated with capital intensity and locational access to specialised facilities and equipment, as well as difficulties associated with health and safety requirements in what is a highly regulated sector due to the safety needs associated with handling and disposing of chemicals[4].

Evidence from the UK Innovation Survey provides a robust picture of innovation activity and the barriers to innovation in chemistry SMEs and other SMEs. To gain a more detailed insight into innovation in chemistry SMEs we used our interviews in Phase 1 and Phase 2 of the project to explore the distinctiveness of innovation in chemistry SMEs. Respondents differed in their view as to how distinct chemistry SMEs are, but this depended on the comparator. Some commented that science R&D is very different with very different requirements to software R&D, for example, especially in terms of the equipment and facilities needed.

[3] See https://www.rsc.org/contentassets/ac8d2c6af02c47bca32ce94be35a4293/workforce-summary-report.

[4] See https://www.rsc.org/globalassets/04-campaigning-outreach/campaigning/science-horizons/science-horizons-report.pdf.

This need in science, perhaps especially chemistry, for more complex facilities and long-term funding is also associated with the longer time required for development, echoing RSC's earlier study, for example:

'Firstly, you've got to develop bench scale processes, and then pilot it, and then take it to commercial scale. And each of those requires technology transfer and optimisations and so on. And then generation of all the quality data that goes with the process, and its scale up. And three years is nothing in this. In contrast, in software, if you haven't got your idea to market in three years, it's dead in the water' (Chemistry industry expert).

Whilst most respondents were clear about the difference between the development requirements of establishing chemistry-based and software firms, the distinction between establishing chemistry-based and other science-based SMEs was sometimes less clear. There is a general perception that while other sciences shared many of the same challenges, there are perhaps three areas in which establishing chemistry-based SMEs differ from other science-based SMEs:

- The foundational nature of chemistry and the consequent diversity of the market for chemistry products often makes it difficult to identify the best target markets. One of our Phase 2 interviewees commented: *'chemistry covers a broad range. It's enabling technology, which spans everything from biopharma through to petro-chemicals and polymers, speciality chemicals' (Expert, Platform Technologies)*.
- There is less critical mass in chemistry with less specialised equipment, fewer specialist or 'sector savvy' investors and fewer exemplars of success than, for example, in biotech. One of our interviewees commented: '*the biotech industry in this country is incredibly strong and has some super role models and a well-established financing mechanism – lots of money, lots of great exemplars' (Expert, Platform Technologies)*.
- The particularly long development times from lab to market for chemistry technologies mean that financial, skills and other challenges during the development process are more acutely felt in chemistry than in other sectors.

"I think it is a general issue ...and not necessarily limited to the chemical sector, although I think within chemicals it is particularly challenging because of the scale of what's involved" (Sustainability SME).

"When things work well in the lab, great, but it's a very different story to manufacture things in large quantity, we again and again face something just not scaling up the way it was working in the lab or properties not matching what we felt we could achieve before running an industrial pilot" (Sustainability SME).

3.5 Summary

Data from the UK Innovation Survey suggests that chemistry SMEs are approximately twice as likely to be investing in R&D as other SMEs and also more likely to be investing in other innovation activities. They are more likely to be engaged in new to the market innovation, with 16 percent of SMEs in chemistry-intensive sectors involved in new to market product or service innovation compared to 9 percent of all SMEs and 8 percent of Chemistry SMEs involved in new to market process innovation compared to 4 percent of other SMEs.

Chemistry SMEs are more likely to collaborate in their innovation activities than the general SME population, particularly with universities, suggesting a different type of innovation behaviour in these firms.

Cost, underdeveloped skills and market barriers are all more likely to be reported in SMEs in chemistry-intensive sectors. Finance is also a key barrier. The financial barriers to innovation are often suggested to reflect market failures related to the difficulties for firms and their financiers in assessing *ex ante* the returns from innovation and the associated risks. This incomplete information suggests that firms will tend to under-invest in R&D and innovation activity and has long been a rationale for fiscal policy intervention. The barriers to accessing finance are likely to be greater where firms are engaging in new to the market innovation which has high up-front innovation costs and long project durations.

Figures from national data sets do allow us to compare the experiences and strategies of chemistry SMEs with those reported by other sectors but do not directly capture the challenges faced by deep tech firms. Those firms founded in underlying IP, novel technological advances and that require concerted R&D investment to move to market are not identifiable through these data sources. In terms of the UK Innovation Survey, they may also be excluded from the survey due to having fewer than 10 employees or being in the pre-revenue stage and therefore not included in the sample sources used to select respondents. This group of firms is the focus of the next Section.

4. Understanding deep tech chemistry SMEs

4.1 Introduction

In this section we present evidence from our qualitative research with deep tech chemistry SMEs and sector experts to explore their experiences of the challenges to, and enablers of, innovation. The challenges faced by deep tech firms were often complex and multi-dimensional and had typically changed as the firm and its technology moved from the laboratory towards a market application.

The firms interviewed in this research were selected to represent four diverse technology application spaces: climatetech, platform chemtech, medtech, and biotech. The SMEs interviewed in the climatetech sub-sector are engaged in carbon capture, use of nano materials for the photonics industry, the supply of silicone materials for use in lithium-ion batteries and plastics technologies. Their role might be characterised as one of contributing a less visible component or process to a bigger product or broader activity. They are seeking to meet a demand derived from the net zero challenge, e.g.:

> ***'in terms of getting more performance from your batteries for longer driving range, faster charging, this is where materials like silicon can make a positive contribution' (Net Zero SME)***

In the medtech and biotech sectors respondents included several businesses developing improved treatments for various cancers.

Many respondents stressed the foundational nature of chemistry to many activities within this sector:

> ***'We have made advances with many invasive human diseases but there are still a lot of people dying from the big ones, cancer, heart disease. But chemistry is really the cornerstone of [addressing] all of that' (Health and Pharma SME)***

Finally, the SMEs involved in platform chemtech are engaged in the discovery of a new molecules; the production of super-black-absorbing materials; the development of a multi-purpose flow reactor and the design and manufacture of metal-organic frameworks, a class of super-absorbent nanomaterials with global impact. All of these products had multiple potential applications.

4.2 Challenges and enablers in deep tech development

The deep tech firms we interviewed highlighted a wide range of challengers and enablers of development. We group discussion of these factors under the following headings:

- Innovation leadership skills
- Finance and Funding
- Equipment and running costs
- Technical skills and recruitment
- Accessing advice and networks
- Location
- Collaboration and Intellectual Property

We treat these themes separately here but recognise that many of these are interconnected, e.g. access to existing equipment might reduce the need for finance, access to skills and equipment might be made easier by location.

4.2.1 Innovation leadership skills

Within this broad heading, we identified many different skills and abilities needed by the business leader and the challenges in combining these skill sets. One of our experts identified the need for a team of three at the top of the deep tech enterprise:

> ***'your top team is usually a CEO, a chief technology or scientific officer, and possibly a business development officer. That triad usually forms the core of a spin-out' (Chemistry Industry Expert)***

This reflects the diverse skills needed by firms' leadership teams, which go beyond 'management and leadership' or 'entrepreneurial' or other common descriptions of the skills of business leaders. A lack of any one of these skills amongst the leader or team can, we were told, impact on the success of the enterprise:

- Ability to identify markets and to commercialise innovation
- Ability to access finance – identification of the right sources and ability to communicate effectively with potential financiers
- Ability to access and make use of advice
- Ability to access, retain and nurture skills and talent
- General business management skills
- Absorptive capacity; the ability to assimilate and apply new information to their business is enabled by workforce skills and leadership quality.

The ability to identify the most appropriate market for the product is one of the main challenges for establishing deep tech chemistry SMEs, and one which most experts reported that SMEs found difficult:

> ***'One of my biggest frustrations is how things apply in the real world, how the theory applies … thinking about both the financial aspect and the implementation aspect' (Chemistry industry expert)***

We have seen that some chemistry SMEs' innovation is foundational and may have a wide range of applications. For those involved in developing this type of technology, the challenge of identifying a market may be more severe. For others, which are targeted improvements of a specific product or industry process, there are challenges in delivering those improvements at a cost which incumbent manufacturers are willing to absorb. The firms we spoke to have generally experienced some or all of these challenges and a number had 'pivoted' – changed their direction - as the science developed or as the market changed.

For example, the growth in demand for batteries for cars has shifted the battery market significantly, seeing one SME we interviewed shift from a focus on mobile devices to cars. Similarly, an SME engaged in providing nano materials for photonics had begun in solar, but as solar panels are so price sensitive, their technology would not be viable, so they expanded into different and broader applications and are now licensing their technology for others to manufacture. A company producing black materials began developing equipment for low-temperature carbon energy, but the market was smaller than expected. However, the National Physical Laboratory were aware of the reactors developed and asked if the reactor could be used for making black materials, initially, for use in space technology. Their market and application have expanded, but it is no longer in the carbon energy market (see also Box 4.1).

Box 4.1: Case Study – The journey to revenue is not linear

This SME is currently focused on one application of their new molecule in order to get some products to market quickly and develop an income stream, while continuing to work on the other applications in the background.

Initial focus was on enzymes and detergents which would enable them to wash at lower temperatures, potentially replacing microplastics, so with an environmental benefit. This attracted a £1 million grant through Climate KIC, a European grant fund. Whilst working on this they recognised the need to extract some value from the molecule in the shorter term, because testing and registration of a new molecule is a time consuming and expensive process. The team focussed on odour removal, trying the chemistry at home, removing the smell of nappies, and proving its success, decided to take a consumer product '***from research and lab to the market***'.

They then developed an air freshener, but are continuing to develop the use of the molecule:

'It's generating revenue, but unless we put a ton of marketing budget to it and change the strategy of the business completely – so not a B2B company selling ingredients but more into a [very small scale] consumer product company. You wouldn't end up with a very good revenue stream from just this one set of products. So we don't want to do that but we see that the bigger pie is actually going back to the ingredient because the ingredient can do way more than just the odour side'.

However, being able to demonstrate the use of the product has accelerated commercial relationships. They currently have two small deals with small companies which are using the chemistry to bring a product to market – again more quickly than a larger company would. But again, this is serving to demonstrate the value and application of the chemistry.

The leaders of some platform tech SMEs had to adapt their original intended markets and applications and were flexible in that approach. One of the SMEs interviewed reported this is an important challenge, as it enabled them to become more realistic in their target product and market (Box 4.2):

> ***'I think some difficulties are good difficulties to have for a start-up to kick-off with'. (Net Zero SME)***

These SMEs were so far succeeding, though they may still pivot at some future point and are still in the process of developing a commercially viable and successful product.

Another problem identified by some of the experts we spoke to is a lack of knowledge amongst business leaders on where and how to access the right finance (this is aside from the issues of access to finance described below) and the ability to speak to investors in a language they understand. For example:

> ***'Sometimes they don't even know where the finance can come from, where the investors are and how do they leverage those connections and get the money? Do they know how to make a good pitch to get the money?' (Health and Pharma expert)***

Many innovators recognise these problems and seek to recruit business leaders, however, high quality commercial leaders might be too expensive for them to recruit unless they have the investment to attract top talent (which becomes a vicious circle). Additionally, more 'non-innovation' management skills were identified by some respondents as being absent with one respondent citing:

> ***'Generally speaking, teams are pretty ignorant in terms of HR and the law associated with that. You're basically finding out as you're going along. And, hopefully, touch wood, they don't get into trouble. I think general, legal, and ops management. And another area which is pretty badly covered is IT support, particularly cyber security'. (Chemistry Industry Expert).***

Box 4.2: The market as an enabler

Identifying the right market and being able to commercialise one's product or process is a challenge which requires extensive skills to navigate. However, it was also reported that there are numerous opportunities now, driven by mission-oriented innovation policy linked to the sustainability agenda, for example:

'… the good news for us is the market [for batteries] story is a constant positive, continually being refreshed to be a bigger opportunity'. (Net Zero SME)

This not only impacts on the potential for scientific and commercial success but also could help attract talent into the sector:

'..manufacturing and the manufacturing space as a whole has not been attractive for people, and so hasn't tended to attract the high-flying entrepreneurial innovators in quite the same way as, maybe, biotech or some of the other areas. That is changing with the whole sustainability agenda'. (Sustainability expert)

4.2.2 Private funding for innovation

The Innovation Strategy identified the challenges in accessing finance in deep tech SMEs. Access to private finance is both a challenge and enabler in the SMEs interviewed for this research. The firms interviewed had generally been able to access start-up funding. But, amongst the SMEs and sector experts, there is a perception that obtaining funding which could support subsequent growth and scaling is a bigger challenge. This may relate specifically to 'Series B' funding which applies when firms have progressed beyond the start-up stage and are preparing to scale:

> ***'the big gap is at Series B, where companies need a lot of capital'. (Platform Industry Expert)***

This may be a common challenge to innovators, particularly in natural sciences, however, some respondents connected this to be the unique aspects of innovation in chemistry, in particular the length of time needed to develop and test a product before revenue:

> ***'You have to have deep pockets and you have to have a longer-term perspective and people who really understand that sort of investment climate'. (Platform tech Industry Expert)***

The long duration of chemistry innovation projects also leads to risks which while not unique to chemistry SMEs may be more impactful due to the development time needed, namely the risk of a change of ownership or management of investors or investors withdrawing support. Some respondents have experienced this and the need to find financing elsewhere:

> ***'Some investors lose patience. Some funds are consolidated to be different. And so, generally, the longer you take, the more uncertainty you're adding, apart from the obvious one of burning up your cash'. (Net Zero SME)***

One SME, which was set up in 2006 noted that they were able to access VC funding, but argued that it had become harder over time:

> ***'Back then, there was a lot of investment in materials science companies, so we were lucky. Today, I think it would be very different because they're more interested in software-type applications because they get much better exits and multiples'. (Net Zero SME)***

The research suggests that investors are also less likely to invest in innovation which they do not understand or cannot see. This can pose a challenge for the innovator but also represents a potential risk to investors in missing opportunities if they are not able to fully understand and appreciate the market potential of a chemistry innovation. 'Sector savvy' investors are reported to be a positive enabler by some of our respondents, investors who understand the science and the markets.

4.2.3 Public funding for deep tech chemistry SMEs

Respondent businesses tended to see real merit in grant funding for early-stage SMEs. For example, small, voucher grants have helped them develop the technology along the way by buying time or access to equipment to answer proof of concept questions:

> ***'We've had Innovate UK grants and that's been very helpful - in fact that's what we formed the company around'. (Health and Pharma SME)***

Many of the SMEs we spoke to have also accessed public funding for subsequent innovation. The key reported concern in accessing public grants lies with the perceived burdens associated with the grant application process. However, some recognised that a large part of the problem there is a lack of understanding of what makes a convincing application:

> ***'For an SME that is not used to filling in grant applications, it can seem really bureaucratic, and yes there is a sort of methodology as to how you fill these in. But I guess, cynically, the selection becomes the art of how you fill in forms as opposed to actually whether your technology is good enough.' (Health and Pharma expert)***

However, for others, it is not their ability to write applications, but that these were often rejected on the basis of criteria which had not been clear in the application guidance, or on grounds which seemed irrelevant to the purpose of the grant. This was demoralising for people who worked on such bids.

There were also concerns about the ability of the people reviewing applications to understand the applications (akin to the need for 'sector savvy' investors):

> ***'on government panels, the people that they select either have no clue about the technology because they're just consultants that are experts in everything'. (Platform SME)***

As we have seen, chemistry innovation is also expensive and takes longer than many other types of innovation. Public funding of 3 years or so duration was seen as insufficient for chemistry development.

> ***'I would say that the use of government grants, and so on - is an essential part of the funding mix to help translate technologies to the market. But the problem with this sort of funding is it's only three years. It's an extremely short period of time to be building up capacity. You're just about getting to the point when everything is working when you suddenly pull the plug'. (Chemistry Industry Expert).***

However, there were also concerns expressed that public funding did not recognise these challenges, even though they are well known:

> ***'But there seems to be a logical disconnect in what they know and how they construct funds'. (Chemistry Industry Expert).***

An additional issue with this may be the difficulty in providing clear milestones in applications given the uncertainties in chemistry testing that are not shared across all innovations:

> ***'Although it takes a long time, you have clear validation points of success along the way. That is not so transparent and clear in the general chemistry space. And so those are a bit of a challenge for the development of chemistry-based businesses because of that period of time, and, therefore, the risk profile and return needs of investors'. (Sustainability expert)***

Overall, our interviewees emphasised the importance of public funding to support commercialisation, particularly in the early stages of development. Many of them had benefitted themselves from public grant support. There were consistent concerns, however, about whether review panels understood the specific challenges of chemistry innovation and its support requirements. The duration of many chemistry innovation processes was not thought to be reflected in grant durations. Other interviewees suggested that SMEs themselves, however, also need to develop a stronger knowledge of public funders' requirements in applying for grant support.

4.2.4 Equipment and running costs

One of the main challenges identified by almost all the deep tech chemistry SMEs we interviewed is the availability of suitable chemistry lab space and associated facilities. This applies at all stages of development: initial availability of lab space; testing the production process for larger quantities; and scaling to larger manufacture. University spin-outs typically have some initial access to labs, though for one firm, this is expensive (at £15,000 per annum per chemist) and is restricting recruitment of key staff. For a non-university spin-out, access seemed more problematic until they found a space on a science park. However, to test and demonstrate effectiveness, larger scale testing becomes necessary. A common problem across the deep tech chemistry SMEs we interviewed was the need to be able to provide samples on a scale sufficient to convince large manufacturers to adopt the new technology, e.g.:

> ***'You also need to have a set of equipment that can make the material at scale even during the material development phase to be able to test it and, ideally, sample it to customers. So, it's not a question of making a few milligrams. We need to be able to make hundreds of grams, and then kilos, and then hundreds of kilos. So, the process development and scale-up need to be linked into that as well'. (Net Zero SME)***

Firms may consider collaborating with a manufacturer at this stage, to share the costs and expertise required for testing at a greater scale (Box 4.3). However, access to larger chemical manufacturers (with a capacity of tons) in the UK was said to be problematic:

> ***'You don't have a huge pool of good ton manufacturers to begin with for chemistry and then you have even fewer that are game enough to try brand new ways of doing things' (Platform SME)***

One expert noted that while the plant is needed, so too are the skilled people to operate it:

> ***'It's about assets, but it's about people as well. So, somebody who knows how to run a pilot plant is a highly skilled individual'. (Platform tech Expert)***

Access to specialised equipment is a recurring theme in our research and one which is seemingly an important differentiation between chemistry from other natural sciences.

The decision to manufacture or not is a critical point in the journey of deep tech chemistry SMEs, and there are a number of choices to be made at different stages of the development process. To some extent the route taken depends on the preferences of the founder/management team, but there are constraints in these choices, such as the availability of facilities at the required scale.

At the earliest stage, a technology developed in a university can be developed through a spin-out or through selling the IP or licensing the technology to an existing chemistry manufacturer.

Having established some degree of success with small scale, bench testing, greater test quantities are required, which requires larger facilities. Leaving aside availability, the SME needs to decide how to approach this, whether to:

- buy/develop their own kit;
- send samples to customers to test themselves (once IP and non-disclosure signed)
- work with others to test/build for them.

These choices apply as the technology is tested on a bigger scale moving on to manufacturing. Most of the SMEs interviewed had not entered large scale manufacture as yet. Some were at the stage of exploring the option of doing so whereas others had explored manufacturing themselves and dismissed it as an expensive option and were focussing on which partners to work with and how to scale up and manufacture:

> ***'... so we were talking about maybe us taking control of the manufacturing. Now, we're pretty much going exclusively down the licensing where we would sell it, our know-how and IP to different companies'. (Net Zero SME)***

4.2.5 Technical skills and recruitment

There were mixed views on the availability of technical skills beyond those needed by the entrepreneur discussed above. Some SMEs had difficulties recruiting senior staff due to their location. For example, one SME reported difficulties in recruiting more senior and experienced staff due to their location outside the main engineering hubs around the Midlands. Another deep tech SME reported difficulties in getting senior people to move to Cambridge. Another noted the barrier of not being able to compete with the packages offered by larger firms.

With regard to new graduates, there is mixed opinion as to whether smaller firms were attractive to work in or not, with some citing difficulties in attracting staff due to the potentially risky nature of the business, and others seeing this as an advantage. Questions were also raised as to whether graduates have the right skills for chemistry innovation, with innovation coming from interdisciplinary skills:

> ***'The great, great breakthroughs come at the interfaces between disciplines'. (Chemistry Industry Expert)***

But respondents suggested that universities are moving away from dual honours, and teaching is in less relevant subject specific blocks:

> ***'Our organisation doesn't need just chemists. It needs chemists that understand engineering, understand biological systems, that understand artificial intelligence, IT, etc. So that's the individual you want and it's not the individual that's coming out the system. And particularly in SMEs, people are going to be multitasking, they're going to have multiple roles and going to need skill sets, but a multiple knowledge base as well.' (Medtech SME)***

Other noted shortages were in chemical engineering, biochemical engineering, analytical chemistry skills and the project management skills needed to work on an R&D project. The importance of teamwork and effective team management is cited in our interviews:

> ***'Technology start ups are a team sport ... everyone has to be able to communicate and compromise'. (Net Zero SME)***

4.2.6 Accessing advice and networking

Leaders of deep tech chemistry SMEs need to be able to access the right support to help deal with the array of issues they face, sometimes perhaps for the first time. Throughout our research, questions were raised about the quality of advice available to firms. One respondent noted that university spin-outs can access university business support, which they felt was better than the support on offer through general business support mechanisms. Even so, university Technology Transfer Offices were reported to be widely variable in their ability to support chemistry start-ups, and the individuals themselves tend to be generalists, without an understanding of the specific technology, markets, or regulatory regimes (particularly important in chemistry innovation) and do not necessarily have a business background:

> ***'The universities will say, well, we have schemes to help people. But you have to argue, universities are not the right people to be supporting new entrepreneurs because that's not their business. That's not what they're good at'. (Health and pharma SME)***

Peer to peer learning through business and social networks can be an important additional resource for SMEs. There is good evidence that networking can increase motivations, confidence and dynamism in SMEs generally[5]. Access to these networks may well be more difficult in the UK than elsewhere because there is less strength in depth in chemical companies than in other parts of Europe (except for pharmaceuticals and oil and gas). Again a possible side-effect of the lack of critical mass in chemistry in the UK. However, not all expertise comes from other chemical companies. Many SMEs need to tap into their potential markets or work with other start-up companies, accessing a range of knowledge and connections. The science park location of one of our SMEs facilitated informal networking and collaborations with other diverse businesses and casual access to academics which has provided opportunities for them.

4.2.7 Location

Respondents tended to see the spatial clustering of chemistry SMEs as being important to their success. The agglomeration effects of clusters of firms operating in a similar environment enables employment mobility between firms and more relevant support and collaboration opportunities which are so vital to establishing SMEs.

Generally, it is reported that both government funding and private sector investors favour businesses located in the so called 'Golden Triangle' of Oxford, Cambridge and London. Some respondents argued that the advantages for an SME in being located in the 'Golden Triangle' extend well beyond finance however and, conversely, that being located elsewhere tends to create disadvantage:

> ***'Cambridge is part of the Golden Triangle - Oxford, Cambridge and London. It is well known and established, in legend and in truth, that the venture capital community of London is very London centric. We have our own ecosystem here in Cambridge. But we also have the benefit of being close enough that in non-pandemic times, at least, we can attract people up out of London. We also have the cachet of an internationally prestigious university to mean that we can also interest international investors, particularly those from the US'. (Health and Pharma SME).***

Outside of the 'Golden Triangle', access to venture capital is reported to be particularly problematic as there are fewer investors willing to invest in time-consuming, expensive innovation in other parts of the country, fuelling a vicious cycle of fewer such innovations:

> ***'I think there are projects in the regional universities but they're just not visible, [and] VCs will not leave the M25 unless they're going to Oxford or Cambridge. But that doesn't mean there aren't great projects outside Oxford London and Cambridge'. (Health and Pharma SME).***

One respondent did report that there are traditional areas of chemical strength in the UK which have the potential to be built upon (e.g. the North East), but arguably, they do not have the advantages of critical mass, financing or reputation that occur South East, thus presenting a different locational challenge for SMEs, even in these days of virtual networking and conferencing. Depending on where you are, location is either a challenge or an enabler.

[5] See https://esrc.ukri.org/files/news-events-and-publications/impact-case-studies/lead-an-innovative-programme-for-developing-leadership-in-smes-lancaster-university-management-school/.

4.2.8 Collaboration and IP management

The high level of collaboration among chemistry SMEs for innovation was evident from our analysis of the UK Innovation Survey although the survey also suggests that significant barriers to collaboration remain. The need for collaboration was also recognised by almost all interview respondents in order to access expertise, finance, equipment or regulatory requirements which the SME will not have themselves:

> ***'[Collaboration is] absolutely critical. In all aspects. From scaling the business, to bringing in expertise and skills, to bringing in the networks of competency and expertise, to partnering, to getting global reach in your customer engagement processes. It should be all-pervasive through the company'. (Sustainability expert).***
>
> ***'Collaboration is absolutely critical. Drug development doesn't happen on its own. We can't run our own clinical trials. We can't run our own animal experiments. We don't formulate the drug ourselves; we outsource that. We don't manufacture our drug. So, a lot of the time, everything we do is in collaboration with other people'. (Heath and Pharma SME)***

Many deep tech SMEs are collaborating with universities as they continue to develop their technology and bid for grant funding in collaboration with universities. And many are, as we have seen, working out how best to collaborate with larger firms who can enable the complex testing and manufacturing processes.

The importance of negotiation and effective IP management for collaboration was frequently reported across the interviews and poor IP management was identified as a significant risk for deep tech SMEs during the early stages of their development. Working with a larger scale producer requires sharing their expertise, which requires a coherent IP strategy:

> ***'There have been challenges around partnerships with other companies, especially when they are potentially adjacent to us in the value chain.... how to deal with IP, and the challenge of being a very small player with very little leverage compared to being an established company'. (Sustainability SME)***

However, some SMEs had taken practical steps to overcome these challenges. One had brought in an experienced IP manager who understood the competitive landscape from an IP perspective and who evolved the patent portfolio to reflect different technical approaches; managed an internal innovation process. This enabled the firm to operate with confidence in the market and to license the process to manufacturers. Resolving IP issues and having a strong patent can help with issues around space and capacity enabling manufacture to be licensed.

> ***'Compared to early days where we were doing paid POCs, now we're in a much stronger IP position so we can now give out free samples to customers, so we can now sort of cast the net even wider'. (Platform SME)***

Some respondents noted the valuable role played by intermediaries, like the Warwick Manufacturing Group, which can serve as a go-between for innovative SMEs and manufacturers. Not having this type of intervention can create delays in understanding how an innovation can or might be applied in the manufacturing process.

More generally, collaboration was seen as being essential across all the SMEs we interviewed, in part, because they had generally (not yet) taken the decision to sell their IP outright. Some had developed sophisticated IP approaches to protect their IP and enable them to work more effectively with manufacturers and with potential customers. Intermediaries can enable the process of bringing innovators together with customers, and many exist, but there would appear to be a question of whether they are comprehensive in their geographical coverage or whether these are known well enough by deep tech SMEs.

4.3 Summary

Our interviews identified the challenges which deep tech SMEs face in accessing finance, including the length of time typically required to develop the technology. There is considerable evidence that deep tech chemistry SMEs take a particularly long time to develop. A feature that this research corroborates through illustrating the complexity of their journey, the decisions required and the range of factors - entrepreneurship capabilities, technology, other management skills, technical skills, finance, equipment, access to good advice, networks, collaboration opportunities and effective IP management - which need to align for success. In all of these areas the SMEs interviewed faced some barriers, and in all of these areas, there are at least some distinguishing characteristics of deep tech chemistry SMEs.

We found that access to finance is becoming increasingly problematic as other technology areas are more attractive to investors, requiring less time, cheaper equipment and are potentially easier for investors to understand the value proposition. Deep tech chemistry SMEs have also encountered difficulties in accessing public funding due to the complexity of the process, unclear criteria and timeframes and milestone requirements which do not align with the chemistry innovation process.

The chemistry innovation process has multiple stages of testing and scaling, requiring specialised equipment which is expensive and less readily available than in other areas of scientific research. Even if equipment is available, it may not be known about or be prohibitively expensive for SMEs. Many collaborate on larger scale testing and manufacturing, but this requires good IP management. The level of risk is increased if the technology does not have a clear market application and therefore there is a need to explore potential markets – as is the case with many enabling technologies. However, it is a challenge they need to overcome. Many SMEs we spoke to had pivoted from their original intended market (sometimes multiple times) as the science developed or market conditions changed.

The development journey of deep tech SMEs raises many issues which challenge the ability of the entrepreneur. Good innovators do not necessarily have the skills to identify a market, value their proposition, develop a business plan which navigates the complexity of chemistry innovation, know where to go for investors and how to pitch (a difficult sell) effectively, identify useful networks and collaborators and deal with IP and regulatory regimes. At the very least, they need access to the right advice, but that may not always be available or of the right quality. The right locality can be an enabler with access to equipment, skills, networks and investors, but the right locality may not attract experienced managerial and entrepreneurial staff.

Access to finance, as recognised by the Innovation Strategy is a challenge for deep tech SMEs, but goes alongside a number of other issues which increase the risk of investing in these firms. These factors are not only evident in deep tech chemistry SMEs but perhaps heightened, with the need for, and shortages of, specialised equipment and a long and highly regulated testing process being distinguishing challenges for chemistry SMEs. Financiers, grant panels and TTOs with a greater understanding of these challenges may be more willing to take informed risks to enable the potential benefits of deep tech chemistry SMEs.

Section 5: The UK policy environment for deep tech SMEs

5.1 Introduction

In this section, we explore aspects of R&D and innovation policy in the UK and a selection of comparator countries with a particular focus on how this influences R&D active and deep tech SMEs in chemistry and other sectors. This sets the context for the policy options that could provide better support to deep tech chemistry SMEs in Section 6.

5.2 Innovation Strategy

The policy context in the UK and the shape of future policy development is set by the current policy infrastructure and new directions signalled in the Innovation Strategy (July 2021). This reaffirmed government's ambition to put R&D and innovation at the centre of future policymaking while at the same time recognising many of the challenges and enablers of innovation success identified in our research. Of particular interest is the case for evidence-based intervention to support deep tech SMEs outlined in the Innovation Strategy:

> ***'The case for government to promote innovation in deep and transformative technology is strong. Prospective investors and customers of deep tech may be unwilling to take chances on new and unproven technology or may not fully understand its potential. The journey of tech- based innovation to market can be long, complex, and often non-linear. The UK excels at certain stages of this process but is weaker at others. We should pursue these signals of weakness and address the underlying issues. … The UK government can build on that model, identifying barriers to innovation that are felt acutely in deep and transformative tech, and articulating how government can empower industry to overcome them'.***

This applies to all deep tech firms and is not specific to deep tech chemistry firms. But the case made for intervention here resonates with our own research into deep tech chemistry SMEs, with a long, complex and non-linear journey from discovery to innovation and wary investors and customers. The case may be slightly more pronounced or slightly different for chemistry, but addressing the weaknesses identified by the Innovation Strategy would represent a significant step forward.

The Innovation Strategy recognises the need to focus support on a group of Missions and key Technologies, which are defined as:

> ***'Innovation Missions and technologies are separate but complementary. Missions are about a clear and measurable outcome, such as vaccinating the UK against COVID-19, for which we need to draw on multiple technologies and research disciplines, work with different industries and supply chains and tackle innovation, manufacturing, and logistical challenges. Technologies, such as AI or genomics, will be vital for tackling these challenges but we may not know from the outset precisely how they will help'.***

To support this objective, the Innovation Strategy lays out plans to:

- Establish a new Innovation Missions programme to tackle some of the most significant issues confronting the UK and the world in the coming years.
- Identify the key seven technology families that will transform our economy in the future.
- Launch new Prosperity Partnerships to establish business-led research projects to develop transformational new technologies, with £59m of industry, university and public investment.

The Innovation Missions Programme will be developed, and the specific missions determined by the new National Science and Technology Council. The Innovation Strategy says these missions will be in the priorities covered in 'Build Back Better: our plan for growth' and 'The Integrated Review of Security, Defence, Development and Foreign Policy', they will build on existing or potential competitive advantage and generate a wealth of societal and economic benefits. Our analysis suggests there is a potential contribution for deep tech chemistry SMEs across a number of these Missions. Examples of where chemistry innovation is making an impact are:

- Clean, affordable energy; for example, battery technologies; solar technologies; materials science; thermal energy storage.
- Better health and medicine; for example, drug discovery and development; drug delivery systems; diagnostics; improved treatments and therapeutics.
- Circular economy; for example, novel recycling and reuse technologies or processes across a wide range of applications (including food waste, textiles, packaging, or industrial waste).
- Combatting climate change and its impacts; for example, carbon capture; conversion of CO_2 into energy and/or materials; development of renewable energy sources.
- Equitable provisions for basic human needs; for example, improved water quality and sustainable water ecosystems.
- Sustainable food systems; for example, development of alternatives to traditional agricultural practices; development of seed coatings for hostile growth environments; conversion of food waste; improved food labelling.
- Responsible consumption and production; for example, development of biodegradable packaging and other materials; creation of environmentally friendly compounds and ingredients.
- Sustainable industrialisation and process technologies; for example, green chemistry; development of non-toxic and renewable reactants, solvents, catalysts or additives; development of nontoxic and renewable coatings and materials.
- Reducing and reversing adverse environmental impacts; for example, recovery of pollutants and waste materials.

The Strategy also pointed to a number of initiatives of interest given the particular challenges chemistry SMEs face, such as training for investors to be led by UK Finance, the British Business Bank etc. These will build on the current support systems and polices in the UK, which are now described in brief below.

5.3 R&D and innovation support in the UK today

UK R&D spending is approximately 1.7 percent of GDP, lower than that of our major international competitors and this gap has been growing as other countries have increased R&D investment levels. In light of this gap, increasing the level of R&D spending has become a significant UK government target in recent years with the Industrial Strategy[6] re-iterating the aim to raise total research and development investment to 2.4 percent of GDP by 2027 (from 1.7%)[7].

The Industrial Strategy also recognised that the UK is better at research than development, citing examples of where the UK is unable to maximise the full value of its science (e.g. lithium ion batteries bought up internationally) and goes on to say:

'Much of our innovation tends to be in areas such as software and branding, including marketing and advertising, which often require less patient capital to fund them. We are good at low-cost innovation and flexible start-ups but the long and patient process of getting a new technology to market is difficult. As a result, many of our innovative businesses are nimble, flexible and imaginative but do not grow to be substantial, big or strong. There are exceptions, but in general British businesses' R&D tends to favour quick routes to market, rather than long development times, and selling businesses to growing them'.

[6] https://www.gov.uk/government/topical-events/the-uks-industrial-strategy

[7] This target remains

There is a general recognition in the Innovation Strategy that in the past commercialisation processes in the UK have not worked as effectively as those in other countries, particularly the US. The Innovation Strategy points to the need to better facilitate the transfer of science into industry and support scale up to full scale manufacture to deliver the long-term value from innovation to the UK.

The weaknesses of commercialisation processes in the UK apply particularly in the case of smaller companies – such as deep-tech chemistry SMEs - which are under-represented in most indicators of university-business interaction. Data from the Higher Education – Business and Community Interaction (HE-BCI) survey provides an overview of university-business engagement and in terms of intellectual property (IP) income. For example, only around a fifth of university IP income is associated with SMEs with the remaining four-fifths accounted for by larger firms. Broadly similar compositional profiles apply to each of the other commercialisation channels identified in the HE-BCI survey[8]. As noted earlier, however, SMEs account for around 40 per cent of UK private sector GDP. Along with concerns raised by our interviewees around finance, advisory services and premises, this suggests that barriers remain to effective support for commercialisation in deep-tech SMEs.

Data from the HE-BCI survey and our own interviews also emphasises locational and institutional contrasts in the commercialisation landscape with different universities having different priorities in terms of commercialisation, incubation and business acceleration activity[9]. Technology transfer capabilities and links to potential sources of investment also differ markedly between institutions as does success in accessing national schemes such as Knowledge Transfer Partnerships. Combined with the variability of quality related research funding between institutions, and in keeping with some of the views of key informants set out earlier, it is evident that there is considerable geographical variation for chemistry SMEs seeking support from their local university and associated networks. This emphasises the significance of the earlier discussion about spatial variations in the support available for chemistry and deep-tech chemistry SMEs outside the Golden Triangle. A focus on building the strength of local eco-systems has been identified as a priority area in recent international discussions of commercialisation activity[10].

In the next section we consider the effectiveness of current UK innovation policy, and in Section 5.5, we consider some international comparisons and the effectiveness of policy as it relates specifically to R&D active chemistry SMEs.

5.4 How effective is UK R&D policy?

Evaluating the impacts of R&D and innovation policies is difficult due to the long timelines between investment and outcomes and strongly asymmetric outcomes – a few highly successful projects often account for a large percentage of the benefits. A high proportion of government schemes designed to promote and support R&D and innovation in the UK have been evaluated, but not in consideration of deep tech chemistry SMEs. Most of these evaluations show some positive impacts although there are consistent methodological challenges related to short evaluation timelines, limited consideration of externalities and social benefits and a lack of reliable estimates of displacement and deadweight.

[8] https://www.ukri.org/wp-content/uploads/2021/10/RE-01102021-IPRelatedCommerialisationActivitiesUpdate-2018-2019.pdf

[9] https://re.ukri.org/documents/2019/developing-university-spinouts-in-the-uk-tomas-coates-ulrichsen-v2-pdf/

[10] https://uidp.org/wp-content/uploads/2020/08/UIDP_final-Oxford-report.pdf

In 2015 the What Works Centre for Local Economic Growth published the findings from a systematic review of evaluations of policies that aim to support innovation through increased research and development (R&D) in the UK and other OECD countries[11]. The Centre makes it clear that the evidence is partial, but they report that the available evidence shows:

- R&D grants, loans and subsidies can positively impact R&D expenditure, and can raise innovative activity in recipients, although not consistently. The effects differ across types of innovation and are weaker for patents than for (self-reported) measures of process or product innovation.
- R&D grants, loans and subsidies can positively impact productivity, employment or firm performance (profit, sales or turnover). There is some evidence that support is more likely to increase employment than productivity.
- R&D grants, loans and subsidies are more likely to improve outcomes for small to medium-size companies than for larger ones. In part this may be because for larger firms, public support makes up a relatively small amount of overall R&D spend, so positive effects are harder to detect. Smaller firms may also be more likely to formalise processes in anticipation of, or response to, a grant, so that some innovation-related spend is reclassified as R&D.
- R&D Tax Credits can positively impact R&D expenditure, although, again, effects are not always positive. SMEs are again more likely to experience positive benefits.
- Programmes that emphasise collaboration perform better than those that just support private firms (as well as those where the programme focus is unclear). Encouraging collaboration might have an additional positive effect on the likelihood that an R&D support programme generates positive effects on outcomes of interest.
- Programmes that target particular sectors appear to do slightly worse in terms of increasing R&D expenditure and innovation, compared to those that are 'sector neutral'.

In addition to formal evaluations, we can consider policy reviews to provide insight into the effectiveness of UK policy. For example, a number of useful reviews of the UK spin-out landscape have been undertaken in recent years stressing the relatively stable number of university spin-outs each year, the concentration of activity in a relatively small number of top UK universities and the complexity of the funding landscape[12].

Business angels and private equity funders play a key role in the early stages of a spin-out's lifetime, supporting around a quarter of cases by public grant funding or funding for collaborative research[13]. University strategies on funding and taking an equity stake in spin-outs vary widely with one recent study finding that university equity stakes in spin-outs ranged from 5 percent to 66 percent[14]. Other studies have stressed the personal issues faced by those spinning-out companies including time pressures, conflicting academic and commercial incentives and objectives and difficulty in accessing appropriate resources[15].

In reviewing licensing, university IP and spin-out, a 2018 study for BEIS[16] found 6 factors influencing these commercialisation activities:

- skills and experience of university commercialisation staff;
- leadership and management;
- interpersonal relationships;
- local economic conditions;
- funding; and,
- availability of information.

Negotiation skills and information to support value estimation were identified as recurring issues. University leadership is also important for the prioritisation and allocation of resources to these activities. The Patient Capital Review was recognised as helpful in addressing funding barriers, including the £2.5 billion Investment Fund at British Business Bank[17]. Given the length of time taken for chemistry research to get to market, this might form a useful source of support for Chemistry SMEs.

[11] https://whatworksgrowth.org/policy-reviews/innovation/

[12] https://www.raeng.org.uk/publications/reports/spotlight-on-spinouts

[13] https://re.ukri.org/documents/2019/developing-university-spinouts-in-the-uk-tomas-coates-ulrichsen-v2-pdf/

[14] https://www.keconcordat.ac.uk/wp-content/uploads/2020/11/Equity-stakes-final-report-18.12.2020.pdf

[15] https://www.enterpriseresearch.ac.uk/wp-content/uploads/2015/07/ERC-ResPap35-M.-Hewitt-Dundas.pdf

[16] Research into issues around the commercialisation of university Intellectual Property (publishing.service.gov.uk)

[17] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/661397/PCR_Industry_panel_response.pdf

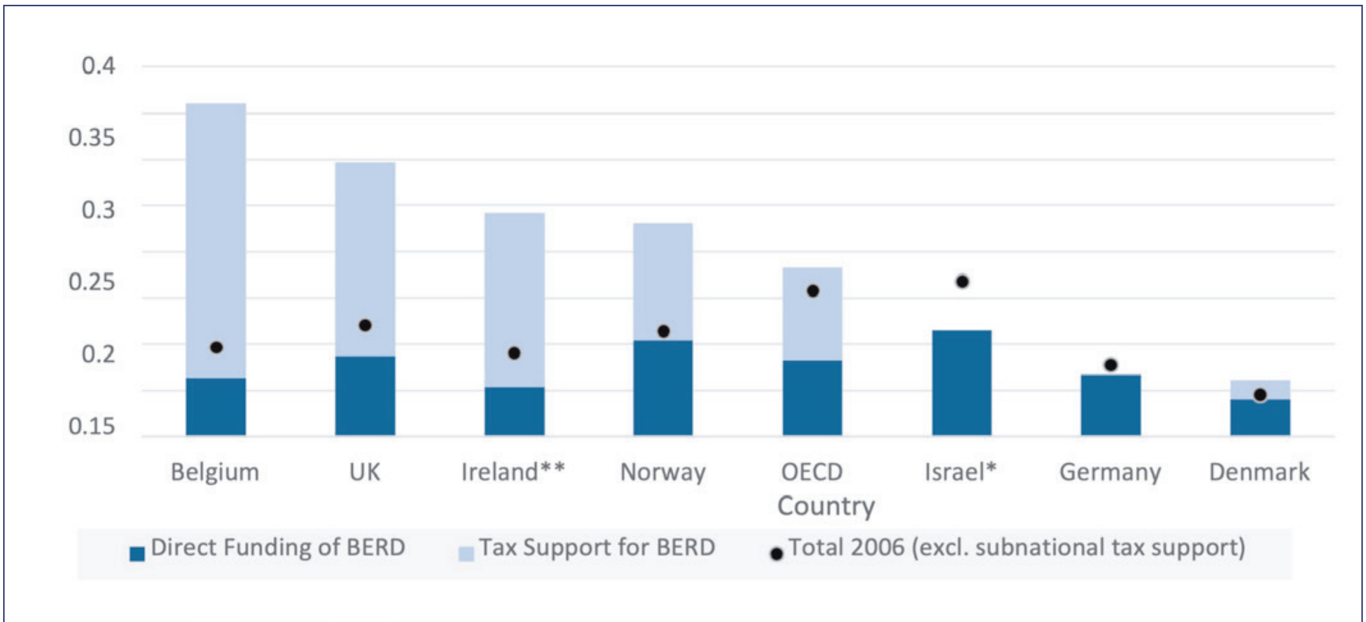
5.5 International policy - differences and commonalities

For this study we undertook a review of innovation policy in a small number of countries, to explore how the UK differs in key respects of importance to deep tech chemistry SMEs.

A 2020 review of innovation policy in eight countries (including the UK) concluded that there are similarities in the broad descriptions of innovation policies across countries, but also differences in the detailed application and in the mix of policy instruments available to firms (Mulligan et al, 2020). The report shows how government support for business R&D (BERD) has increased in most of the countries reviewed between 2006 and 2017 and how this breaks down between direct government support (e.g. R&D grants) and indirect government support (e.g. R&D tax credits). Figure 5.1 shows there were particular increases in the percentage of GDP allocated to BERD in Belgium, the UK and Ireland. Also, the majority of the countries were shown to have a higher percentage of indirect support than direct support (the data precedes the introduction of a Federal R&D tax credit programme in Germany in January 2020). Denmark has the lowest overall level of support for firm level R&D, relative to GDP.

However, Denmark's R&D Tax Credit are only applied to loss making firms – focussing support on early stage, pre-revenue spin-outs.

Figure 5.1: Government Support for BERD, 2006 and 2017



Source: Mulligan et al (2020)

The same report explored innovation policies in more detail which allow us identify initiatives focused on SMEs which do not have a clear UK equivalent or where there are differences in approach:

- Germany, Denmark and Norway have specific measures which support SMEs to collaborate. For example, the *Industrial Collective Research* programme in Germany offers direct grants for R&D projects carried out by sectoral research institutions. The programme is only accessible via sectoral research institutions that are members of the Federation of Industrial Research Association. These institutions have been founded by groups of established SMEs from certain sectors to carry out R&D in their joint interest. Eligible research projects are scientific and technical, cross-firm oriented and expect to generate new knowledge and bring economic benefits to the group of SMEs. The intention is to promote industry-wide collaborative research, to compensate for the structural disadvantages of SMEs in the field of research.
- While voucher schemes are common, in other countries, voucher schemes were variably aimed not just at established SMEs but also at large firms, specific sectors, geographies or technologies.
- Supporting established and emerging non-profit research companies in 'disadvantaged' regions (Germany).
- Supporting international R&D collaboration (Israel and Singapore were particularly strong on this, with bilateral agreements).
- Focus on specific sectors or technologies – making grants or loans available for specific priority areas such as financial technology in Singapore or the environmental sector in Norway. We could find no example of initiatives targeted specifically at the chemistry sector internationally. For policies which focus on specific industries or technologies, they broadly do not differ from other types of policy, in terms of their qualification criteria or the type of support offered.

Box 5.1: Supporting innovative SMEs in Korea

Since the 1990's, large firms in Korea have responded to international competition by increasing investment in R&D and the government has supported research infrastructure. Recognition that SMEs played a weaker role in the innovation system led to a certification system for innovative SMEs linked to a range of policy benefits[18]. Partially repayable grants have also been used to support technology development in SMEs. The SME Technology Innovation programme, for example, supported task specific activity within SMEs in the form of 50% central and 25% local government support for one or three years. The government received back 30% of the contribution as a technology fee for five years. Business Incubators and management innovation policies also provide customised support for SMEs. However, the OECD reported SMEs in Korea as a 'bottleneck' in 2009 (OECD, 2009).

More recent analyses suggest that large manufacturing conglomerates remain the main performers of business R&D, with SMEs and young firms playing much smaller roles[19]. However, continued policy commitment has led to the share of R&D investment going to SMEs increasing from 12.4% in 2011 to 18.0% in 2015. The government has created a dedicated fund through participation in the "Growth Ladder Fund" and the "Korea Fund of Funds", and large companies collaborate with the Centres for Creative Economy and Innovation (CCEIs) to meet funding needs tailored to each stage for start-ups and SMEs. These policy initiatives in Korea are unusual in placing an explicit focus and priority on SMEs (both established and emerging) and seeing this group of firms as a long-term strategic priority for investment within the broader innovation eco-system.

- Of the countries investigated here, only the UK offers a differential rate of R&D Tax Credit for small firms and, as shown by the What Works Centre for Local Growth, Tax Credits are likely to have a more positive impact on small firms. In Denmark the applying entity (firm or self-employed individual) must be loss-making. The benefit applies only to the part of the losses that can be attributed to R&D activities. This explains Denmark's lower overall expenditure shown in Figure 5.3 but is more targeted on pre-revenue activities.
- Italy and Korea certify innovative SMEs, which provide them a range of benefits. In Italy, innovative SME's are defined by the qualifications of staff, expenditure on R&D, whether the company is the owner or licensee of registered patents. They are listed on a public website to foster public monitoring and are a consistent focus of policy attention. Innovative firms can benefit from bespoke and light touch company regulations, tax breaks and simplified access to the national credit guarantee programme. There is some government evidence that innovative start-ups have grown more than they would do outside the scheme.

[18] See https://www.pecc.org/images/stories/publications/SME-2007-6-SME_Innovation_Policies_in_Korea-Kim.pdf.

[19] https://www.innovationpolicyplatform.org/www.innovationpolicyplatform.org/content/korea/index.html

5.6 Summary

Our review of R&D and innovation support in the UK and internationally suggested that the UK has a well-developed national R&D and innovation support system which offers a wide range of public support for innovating firms across the country. Alongside the support offered by the Research Councils and Innovate UK, measures such as the Research and Development Tax Credit, Patent Box and support offered to risk capital by the British Business Bank all help shape the environment for deep tech firms. Internationally, we identified no specific measures targeted at either chemistry SMEs or more specifically deep tech SMEs. Many countries operate a similar grant/tax credit policy mix as in the UK although the relative weights on grants and fiscal supports for innovation varies considerably. Few countries have consistent and different approaches for innovative SMEs. South Korea and Italy have both implemented such SME-specific policy approaches with a more specific focus on innovative SMEs in Italy. In both cases there is some positive impact evidence, consistent with wider evidence of stronger policy additionality effects in smaller firms.

In our interviews with SMEs and industry experts we explored their current engagement with government institutions and policy and noted a range of challenges many of which reflected the issues highlighted earlier (Section 4). Most of these issues were generic to deep tech SMEs, however a number were chemistry-specific or at least impacted more intensively on deep tech chemistry SMEs.

Two challenges stand out in particular. First, within the context of this national system supporting R&D and innovation there is a highly localised dimension to the commercialisation landscape with different universities having different priorities in terms of commercialisation, incubation and business acceleration activity. Technology transfer capabilities and links to potential sources of investment also differ markedly between institutions as does success in accessing national schemes such as Knowledge Transfer Partnerships. Combined with the variability of quality related research funding between institutions, and in keeping with some of the views of key informants set out earlier, it is evident that there is considerable geographical variation for chemistry SMEs seeking support from their local university and associated networks. A focus on building the strength of local eco-systems has been identified as a priority area in recent international discussions of commercialisation activity[20].

Second, the effectiveness of the UK innovation system in supporting commercialisation has been questioned, an issue of critical importance to the success of deep tech firms in chemistry and other sciences. Notable developments have taken place in this area in recent years (see section 5.2.2) but our interviews suggest issues remain around the availability of premises and laboratories, finance, entrepreneurship and leadership skills, barriers to university-business collaboration and the suitability of the current grant regime to deep tech firms. Limitations in the support available for commercialisation often overlap with the regional disparities noted earlier.

[20] https://uidp.org/wp-content/uploads/2020/08/UIDP_final-Oxford-report.pdf.

Section 6: Conclusions and Recommendations

6.1 Introduction

It is generally accepted that R&D and innovation are fundamental drivers of productivity gains and growth throughout the economy. However, the available evidence, reflected in the Innovation Strategy, suggest that the UK lags key competitor countries in terms of investment in R&D and innovation performance particularly our ability to effectively commercialise new discoveries. This is reflected in our own interviews. Interviewees recognised the potential contribution of deep tech chemistry firms to national innovation missions (e.g. net zero, drug discovery) and also identified a range of challenges during the commercialisation process.

In this section we draw together conclusions from the study, set out the case for more effective support for deep tech chemistry SMEs, and outline out a range of policy options for achieving this.

6.2 The case for intervention

The findings from this research provide a substantive, evidence-based, rationale for the development of policy to better support innovation in chemistry deep tech SMEs. The case for intervention to support chemistry deep tech SMEs has two key elements. First, the potential of chemistry deep tech SMEs to introduce innovations which may have very substantial social returns and contribute to innovation missions; and, second a range of market failures which are currently constraining their innovation activities.

Our interviews and the case studies reported in earlier sections suggest the potentially profound impacts that innovation by chemistry deep tech SMEs can have on issues of national and often global concern. Innovation in chemistry is fundamental to achieving potentially transformational breakthroughs in a range of areas from climate change, to developing new treatments for a number of diseases including cancer and to addressing plastic pollution. The implication is that innovation in these firms has the potential to generate very significant social, economic and environmental benefits which far exceed the direct benefits to the businesses concerned. In more technical terms, innovation in deep tech chemistry SMEs can drive very significant and positive externalities suggesting a *prima facie* case for policy intervention.

Market failures may constrain innovation and the available literature and the empirical evidence from this study suggest a number of such failures in the UK. Some of these market failures are relevant to all deep tech companies, others are more specific to distinctive aspects of deep tech chemistry SMEs. The market failures most relevant to chemistry deep tech SMEs include:

- ***Failures in capital markets*** – these failures occur throughout the R&D and commercialisation journey, but may be more impactful for chemistry deep tech SMEs than other SMEs due to the length of their innovation journey. SMEs may struggle with securing funds to establish proof of concept and with accessing the mid-level equity-based funding required to achieve scale and bring new technologies to the market. Research respondents also suggested that there is a particular structural issue with securing angel investment outside of the so called 'Golden triangle' of Cambridge, Oxford and London. Angel investors require a critical mass of investment opportunities in order to spread the risks of their investments. This critical mass does not exist outside of the Golden Triangle. and it remains to be seen whether the pandemic and moves to online working by investors will have, in any way, addressed this issue.
- ***Failures in the market for grant funding*** - It is generally accepted that R&D intensive start-up businesses typically require grant funding to help establish the validity of their technology. The majority of chemistry deep tech SMEs interviewed for this study are generally supportive of grant funding provided by government. However, the application process was also viewed as complex, with unclear success criteria, increasingly competitive and with a higher likelihood of bid failure. Reviewers were often thought to lack an understanding of the potential of deep tech chemistry, a sector-specific issue.
- ***Failures in the availability of premises and specialist equipment*** - There was a very clear view amongst the respondents interviewed for this study that the availability of suitable premises and specialist equipment presents an acute challenge for many chemistry deep tech SMEs, particularly those seeking to scale up. Respondents generally reported a spatial dimension to these market failures which were said to more of an issue outside the Golden Triangle where agglomeration benefits are weaker. This market failure was highlighted as applying specifically to chemistry deep tech SMEs because of the very specific requirements of chemicals production.

- ***Information failures and perceptions of risk*** - There are widespread information failures that result in poorly informed perceptions of risk related to the chemistry deep tech sector. Evidence from our interviews suggests that these information failures affect the decisions of businesses, business support professionals and policy makers. For example, it is widely accepted that collaboration with other businesses, and often with the university sector, is a key driver and enabler of R&D and innovation. Such collaboration may be constrained by exaggerated fears of IP leakage or a lack of advisory support with in-depth sector expertise and understanding. Policy makers, although often concerned to reduce the risks faced by deep tech SMEs, typically also seek to minimise the risks associated with policy initiatives.
- ***Failures in technical and managerial skills development*** – There is extensive evidence that under-developed management and leadership skills are a constraint to SME performance throughout the UK economy (see, for example, Hayton 2014)[21]. Evidence from this study suggest that underdeveloped management and leadership skills, particularly poorly developed entrepreneurial and innovation skills, are both widespread in deep tech SMEs in the chemicals sector and a major constraint on business performance and the commercialisation of their technologies. Indeed, this research has shown that these businesses tend to face challenges in innovation management and leadership that transcend those typically encountered in the general case. In particular, respondents emphasised the inter-disciplinary nature of much innovation and the weakness of multi-disciplinary training.

6.3 Supporting the whole deep tech journey

As the recent Innovation Strategy points out "The journey of tech-based innovation to market can be long, complex, and often non-linear". This is very clearly the case for chemistry deep tech SMEs which typically face an on-going, atypically consequential and long-lasting series of challenges in commercialising their technologies. The key point here is that whilst policy support can be developed to address individual market failures, if other subsequent market failures prove to be insurmountable, the supported businesses may well still not be successful despite the earlier support[22].

Addressing all the identified market failures in a comprehensive package of support is unlikely to be achievable in practice and would be a daunting ask of policy makers. From this perspective, policy makers are more likely to pursue a strategy of identifying and addressing the most widespread and impactful barriers to business success. In later sections we therefore identify a series of policy options which may be particularly impactful for deep tech chemistry SMEs.

A number of the market failures identified in our interviews, however, suggest the potential value of policy measures which have a general rather than a closely targeted impact. Specifically, they emphasise the appropriateness and merits of measures such as encouraging peer-to-peer networking which can have a general impact on ambition, confidence and collaboration[23]. Similarly, our interview evidence provides a compelling case for supporting the development of management and leadership skills which would also transcend the specific constraints involved by enabling businesses themselves to address the challenges they face more effectively.

[21] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/407624/BIS-15-95_Leadership_and_Management_Skills_in_SMEs.pdf

[22] See also https://www.imperial.ac.uk/deep-tech-entrepreneurship/about-us/.

[23] Miao, Y. Z., et al. (2021). "Learning from Technologically Successful Peers: The Convergence of Asian Laggards to the Technology Frontier." Organization Science 32(1): 210-232.

6.4 The purpose of intervention

The Innovation Strategy has highlighted the strength of the case for supporting deep tech companies as part of a mission-oriented innovation policy. This would include many of the innovative R&D active chemistry SMEs. Our research suggests it is vital to understand both the general and the specific needs of these firms and the wider policy environment to enable deep tech firms, across all sectors, to fulfil their scientific and market potential.

The overall objectives for policy in this area might well include increasing both the extent and effectiveness of R&D and innovation in deep tech chemistry SMEs. One approach to this would involve increasing the number of R&D and innovation active SMEs in this sector. However, increasing the number of firms working in this area would, in all probability, accentuate the challenges businesses face as competition for limited resources and support increased. Accordingly, here we are concerned primarily with understanding how establishing and established SMEs in this sector can be more effectively supported to ensure that a larger proportion are enabled to successfully commercialise their ideas and technologies. This requires the creation of an enabling environment by addressing market failures and other constraints which serve to inhibit R&D and innovation.

From this perspective, the key objectives for policy are therefore likely to include:

- Increase the proportion of deep tech SMEs successfully commercialising their ideas and technologies.
- Ensuring that the outcomes achieved are focused on those areas where they can have the greatest social, environmental and economic impacts.

As the specific challenges identified can often be addressed in different ways, we have categorised policy options under four headings, consistent with the four main challenges identified by the deep tech chemistry SMEs we interviewed:

- Access to finance
- Access to bespoke, affordable facilities
- Leadership and management
- Ecosystem and resources/networking and peer-based learning

The recommendations presented here draw on evidence we have heard throughout the research of what works for these firms and what doesn't, and on the UK and policy analysis set out in Section 5. We also consider how these measures can contribute to the effective delivery of the Innovation Strategy.

6.5 Access to finance

The recent Innovation Strategy highlighted the challenges deep tech SMEs face in accessing finance. Indeed, a majority of deep tech chemistry-based SMEs that participated in this research reported being constrained by struggles to secure appropriate finance. Respondents also suggested that issues related to access to finance were also often linked to a failure of business support and the inability of finance organisations to fully appreciate the potential impact of deep tech companies. Addressing these constraints is crucial to securing better outcomes for these businesses in chemistry deep tech but also other science areas[24]:

- ***Proof of concept funding*** – Several respondents to this study highlighted the importance to their businesses of being able to undertake proof of concept research which is often crucial to securing further funding. This was often sourced via EU funding streams most commonly the ERDF. The £10m addition to the UK Innovation and Science Seed Fund mentioned in the Innovation Strategy to provide further early-stage patient capital for high potential businesses is a welcome development and it will be necessary to ensure deep tech chemistry start-ups, with their complexity and multiplicity of market, can secure access to these funds[25].

[24] See also https://www.iop.org/strategy/productivity-programme/innovation-survey#gref%20%20%20%20.

[25] See https://www.ukri.org/news/funding-boost-supports-growing-high-tech-companies-in-the-uk/.

- ***Angel investment*** – Several of the respondents to this study suggested that angel investment remains difficult to access outside of the so called 'Golden Triangle' despite initiatives such as the British Business Bank Regional Angels Programme[26]. The key issue here is argued to be structural – the lack of a critical mass of the businesses in the regions which means that potential investors cannot ensure that the risks they face are reduced by their ability to fund a sufficiently large number of businesses. Consideration might well be given to whether IT based platforms could help to overcome these issues by brokering links between angel investors and potential investment opportunities. This involves reducing the information barriers to investment and allowing investors access to business profiles nationally.
- ***Equity gap*** – Both the academic literature and the responses to this study confirm the existence and significance of an equity gap which means that deep tech chemistry SMEs often struggle to secure intermediate levels of funding to enable scale up and the commercialisation of new technologies[27]. Given the foundational importance of deep tech chemistry SMEs to national and international missions, there is a case for targeted chemistry-specific public support. This would need to reflect the long-term and high risk (uncertainty across multiplicity of markets) nature of investing in chemistry. Our research suggests there is a quantitative shortage of available equity investment, and interviewees perceived chemistry's share to be falling.
- Some of these issues are not unique to deep tech chemistry SMEs but do suggest the value of further policy intervention to create a more enabling financing environment along the lines of the ENABLE[28] programme or National Security Strategic Investment Fund[29]. Measures which might be considered include:
  - The Innovation Strategy refers to work by UK Finance to develop the next generation of lenders (BEIS 2021, p. 25). Our interviews highlighted issues with a lack of understanding of deep tech innovation among both public and private funders. Future developments in this area should therefore consider building understanding of the specific requirements of deep tech businesses in chemistry and elsewhere as well as addressing issues such as IP and intangible assets and ensuring the widespread dissemination of any research in this area.
  - Access to the appropriate public and private funding opportunities should be facilitated through online portals, clearly signposted, and supported as a public good. The need for improved signposting of public support for R&D and innovation has also been emphasised recently by the RaEng[30] and relates strongly to aspirations around 'levelling up'.
  - In terms of private funding, the cost of undertaking due diligence is a key factor limiting the involvement of Venture Capital (VC) in this sector. Accordingly, consideration might well be given to interventions that would underwrite these costs and thereby make the provision of medium sized funding more attractive to VC investors.
  - Public funding – perhaps offered through BEIS, BBB or Innovate UK - could be developed to specifically target deep tech firms across the science sectors to leverage additional private funding.
- ***Grant application processes*** – Given the widely expressed concerns about the appropriateness and effectiveness of the established grant application processes used by Innovate UK and other bodies, there is a strong case for considering whether current processes are fit for purpose in supporting deep tech innovation, and to revise these processes as appropriate. Our research identified a number of specific issues on both the supply and demand side which are constraining deep tech chemistry SMEs' access to public funding. On the supply side, funding timescales - the usual three-year funding opportunities do not allow for the innovation to be fully tested or developed. A lack of flexibility in milestones, and a perceived lack of appreciation by review panels of the challenges involved in deep tech innovation also emerged as issues in our study[31]. These issues could usefully be considered as part of the development of the new UKRI Commercialisation Funding Framework highlighted in the Innovation Strategy (BEIS 2021, p. 45). On the demand side, there is a lack of understanding of what makes a convincing proposal by businesses. Accordingly, there is also a case for training to improve businesses' competences in this area perhaps working through the KTN or Enterprise Europe Network.

[26] See https://www.british-business-bank.co.uk/press-release/british-business-investments-launches-new-100m-programme-to-support-regional-angel-investment/.

[27] See also https://www.gov.uk/government/publications/scaling-the-impact-of-innovation-in-the-united-kingdom/scaling-the-impact-of-innovation-in-the-united-kingdom-cst-letter-to-the-prime-minister-accessible-webpage-version.

[28] See https://www.british-business-bank.co.uk/ourpartners/wholesale-solutions/.

[29] See https://www.british-business-bank.co.uk/national-security-strategic-investment-fund/.

[30] See https://www.raeng.org.uk/publications/other/late-stage-r-and-d-business-perspectives.

[31] See also https://www.ukri.org/wp-content/uploads/2021/11/IUK-18112021-Plan-For-Action-for-UK-Business-Innovation_FULL_WEB-FINAL-26.10.21-1.pdf, p. 40.

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6.6 Access to bespoke, affordable facilities

Given the very widespread perception that the lack of availability of suitably equipped premises is a key constraint on business development and scaling up for deep tech chemistry SMEs, this is clearly an area where intervention would be both practical and useful. Existing sources of information do not appear to be well known or used by deep tech SMEs and better signposting to existing information sources may also be useful. Developing new public/private partnerships for provision may also be useful here[32].

Other policy options under this general heading are:

- Consider gaps in the provision of bespoke incubators/accelerators - The facilities provided by incubators and accelerators are clearly helpful in providing appropriate, suitably equipped, premises (e.g. Unit DX in Bristol, Biocity). Given the particular challenges our interviewees identified for chemistry deep tech SMEs in accessing suitable premises for scaling, an audit to establish what premises are available (for example in established Catapults) would be sensible[33]. This may help to build a case for establishing new facilities specifically designed to meet the needs of chemistry deep tech SMEs. Improving the information available to firms about the facilities which are available would also be potentially beneficial.
- Improving access to flexible equipment - our interviewees stressed the difficulty of funding specialist equipment purchases particularly during the scale-up phase. This is an issue beyond deep tech chemistry firms, and the need for innovative firms to have better access to specialist equipment is recognised in the Innovate UK Delivery Plan 2021-25 in terms of strengthening innovation eco-systems[34]. Consideration could be given to whether public-private partnership investment could help firms obtain access to equipment perhaps through leasing to SMEs working in chemistry deep tech. This would benefit businesses by increasing the availability of suitable equipment while reducing the financial burdens they face.

6.7 Innovation Management and Leadership

If, as argued above, the overall programme of support for chemistry deep tech SMEs must move beyond measures that target specific constraints on performance, the policy programme must include initiatives related to innovation management and leadership.

Perhaps surprisingly our interviews did not suggest any consistent issues around accessing technical skills. Instead, they emphasised the critical impacts on business performance associated with underdeveloped entrepreneurial and innovation management and leadership skills which were widely reported to be a common and significant constraint to business performance. Indeed, there is good reason to believe that deep tech chemistry-based SMEs require particular innovation management competencies beyond those needed in the more general case. Not the least of which are the particular skills needed to successfully manage a business through a protracted period of establishment and commercialisation that will inevitably span a number of years. This strongly reflects the focus in the Innovate UK Delivery Plan 2021-25 on 'enhancing the leadership and commercialisation skills needed by companies to grow their businesses' (p. 51). Among the measures of most importance for deep tech chemistry SMEs are:

- ***Promoting engagement with management and leadership training***. There was a widespread acceptance amongst the SMEs involved in this research that initiatives that aim to develop entrepreneurial, innovation management and leadership skills are necessary and would be useful. However, there is some reluctance to engage with existing training opportunities. Two issues are important here. First, skills development is best achieved through experiential learning rather than being taught per se. Second, the majority of respondents favoured peer-based learning over more formal approaches. The BEIS Peer-networking programme and Help-2-Grow initiative adopt this peer learning approach within each programme, although both are general programmes rather than having a specific focus on deep tech firms[35]. This creates an opportunity for business facing organisations such as the Royal Society of Chemistry to draw on and develop relationships between firms within and across their existing networks.
- ***Developing open innovation capabilities*** – effective collaboration plays a critical role in many deep tech firms' innovation. This requires specific management capabilities: identifying relevant external partners, structuring and managing such collaborative relationships and resolving issues around IP use and ownership. These are critical elements of firms' absorptive capacity – the ability to recognise the value of new information, assimilate it, and apply it to address emergent issues affecting the business (see, for example, Bessant and Trifilova, 2017). There is a strong case for developing these managerial capabilities as part of any management and leadership development programme.

[32] See the suggestions in https://www.iop.org/strategy/productivity-programme/innovation-survey#gref%20%20%20%20.

[33] The Institute of Physics are currently conducting a similar audit of 'innovation centres' for physics based deep-tech firms and aligning any audit with their study would be beneficial.

[34] See https://www.ukri.org/wp-content/uploads/2021/11/IUK-18112021-Plan-For-Action-for-UK-Business-Innovation_FULL_WEB-FINAL-26.10.21-1.pdf, p. 40.

[35] See https://smallbusinesscharter.org/help-to-grow-management/.

- ***Incentivising engagement with formal training*** – given respondents' concerns about the value of formal training programmes, it may be useful to consider incentives that encourage training take-up. One obvious driver that could be employed would be to modify grant application scoring so that applicants who had completed suitable training received a small premium to the scoring of their application. However, it is not clear that this would be well received by either policy makers or businesses.
- ***Encourage the provision of business modules in post graduate training programmes*** – Respondents to this study were also concerned that post-doctoral candidates looking to work in this sector almost invariably lack any real understanding of the non-technical issues faced by these businesses. Accordingly. it would be sensible to review and evaluate the opportunities currently available for post-graduates to develop their entrepreneurial skills while at their university. Several respondents to this study suggested that the Royal Academy of Engineering Enterprise Hub provides an exemplar of effective practice in this area. The Innovation Strategy also highlights the potential value of cross-sectoral training (BEIS 2021, pp57-58). Consideration might also be given to a funded internship scheme through which chemistry post-graduates and subsequently their employers would benefit from the experience and enhanced understanding of the issues involved in working in deep tech-based SMEs. The scope for this type of internship for doctoral students is also recognised in the Doctoral Training Partnership funding provided by EPSRC[36].
- ***Provide better IP and regulatory advice and support*** – Although, as this research confirms, concerns about IP leakage are clearly acting to constrain collaboration amongst some businesses, several interview respondents argued that this issue can be managed. However, there is a need for sector specific IP guidance that considers the complexities in chemistry innovation. Accordingly, appropriate advice on how IP can be safeguarded could be very helpful to many businesses working in this area by providing targeted support through the IPO IP Education Programme (BEIS 2021, p. 39). Within this, universities have markedly different approaches to dealing with these issues. Accordingly, there would be clear merit in securing widespread HEI engagement with best practice in addressing IP and associated licensing issues.

6.8 Ecosystem and resources/Networking

The businesses interviewed in this study highlighted several areas where new policy measures could also contribute to the development of an enabling ecosystem more conducive to business success.

- ***Reducing spatial inequalities*** – There is no doubt that it is, in some respects, easier for deep tech chemistry-based SMEs to operate successfully in the Golden Triangle than it is for them to do so in other areas of the country. This situation is both inequitable and inefficient. Moreover, there are significant diseconomies for SMEs based in London and the South East; not the least of which is often prohibitively high rents. Consideration could well be given to how new clusters of SMEs could be established in other regions of the country[37]. A key issue here would be achieving clusters large enough in those regions to get the various agglomeration effects enjoyed in the South East. There is a clear enough role for incubators and accelerators in addressing these challenges. However, the available evidence suggests that the key issue here is having organisations that are sufficiently large to effectively address the range of challenges identified earlier in this report in a holistic way. Accordingly, there would appear to be clear merit in looking to develop existing regional incubators into more substantial entities capable of comprehensively supporting businesses throughout their journeys from establishment to maturity. While developing large regionally based facilities such as this may appear to be a grandiose and expensive undertaking, the costs to government may well not be prohibitive if private sector buy-in and partnerships can be achieved.
- ***The role of universities*** – We have discussed the importance of the role of universities in delivering or enabling access to national programmes (such as Knowledge Transfer Partnerships) and supporting deep tech chemistry SMEs through their Technology Transfer Offices. Broader engagement with deep tech firms' innovation could also be encouraged through alumni networks and industrial placement opportunities.

[36] See https://www.ukri.org/wp-content/uploads/2021/10/EPSRC-071021-ReviewDoctoralEducationSupport.pdf, p.18.

[37] See also https://www.scaleupinstitute.org.uk/scaleup-review-2020/2020-recommendations/.

- ***Establish and support networking*** – In this report, we have emphasised the need to complement tightly focussed interventions with overarching policies that can support chemistry deep tech SMEs throughout their journeys to commercialising their technologies. We have also noted the scepticism that many of these businesses have in relation to formal knowledge sources and for management and leadership training. Given this context, we see considerable merit in the provision of networking opportunities for chemistry deep tech SMEs. It is generally accepted that networking with their peers expands the ambition, skills, confidence and dynamism of SME owners and managers. Most respondents interviewed for this study agreed with this and were open to participating in such initiatives. Industry representative bodies, local organisations and organisations such as the RSC are closer to these businesses than government and may well be more trusted and better placed to organise and run initiatives of this kind. The value of peer-to-peer networks has also been recently recognised by the Scale Up Institute[38] and in the establishment of the BEIS peer networking programme[39]. While promoting networking may appear to be a 'soft' option not directly linked the challenges concerned, the evidence suggests that it would be relatively inexpensive to deliver and may well be amongst the most effective policy options available to promote growth and innovation in deep tech chemistry SMEs.

[38] See https://www.scaleupinstitute.org.uk/scaleup-review-2020/2020-recommendations/.

[39] See https://www.gov.uk/guidance/small-business-support-schemes-small-business-leadership-programme-and-peer-networks.

References

BEIS (2021) 'UK Innovation Strategy – leading the future by creating it'. Available at: https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it.

Bessant, J. and Trifilova, A. (2017) Developing Absorptive Capacity for Recombinant Innovation. Business Process Management Journal, 23, 1094-1107.

Mulligan, H. (2020). A cross-country repository of details on the innovation and science policy instruments available to firms in eight countries (2007–2020): The devil is in the detail. Ulir.ul.ie. [online] Available at: https://ulir.ul.ie/handle/10344/9543.

OECD (2009) Innovation Policy in Korea. Available at: https://www.oecd.org/sti/inno/oecdreviewsofinnovationpolicykorea.htm. [Accessed 3 May 2021].

OECD/Eurostat (2018), Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg. https://doi.org/10.1787/9789264304604-en.

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