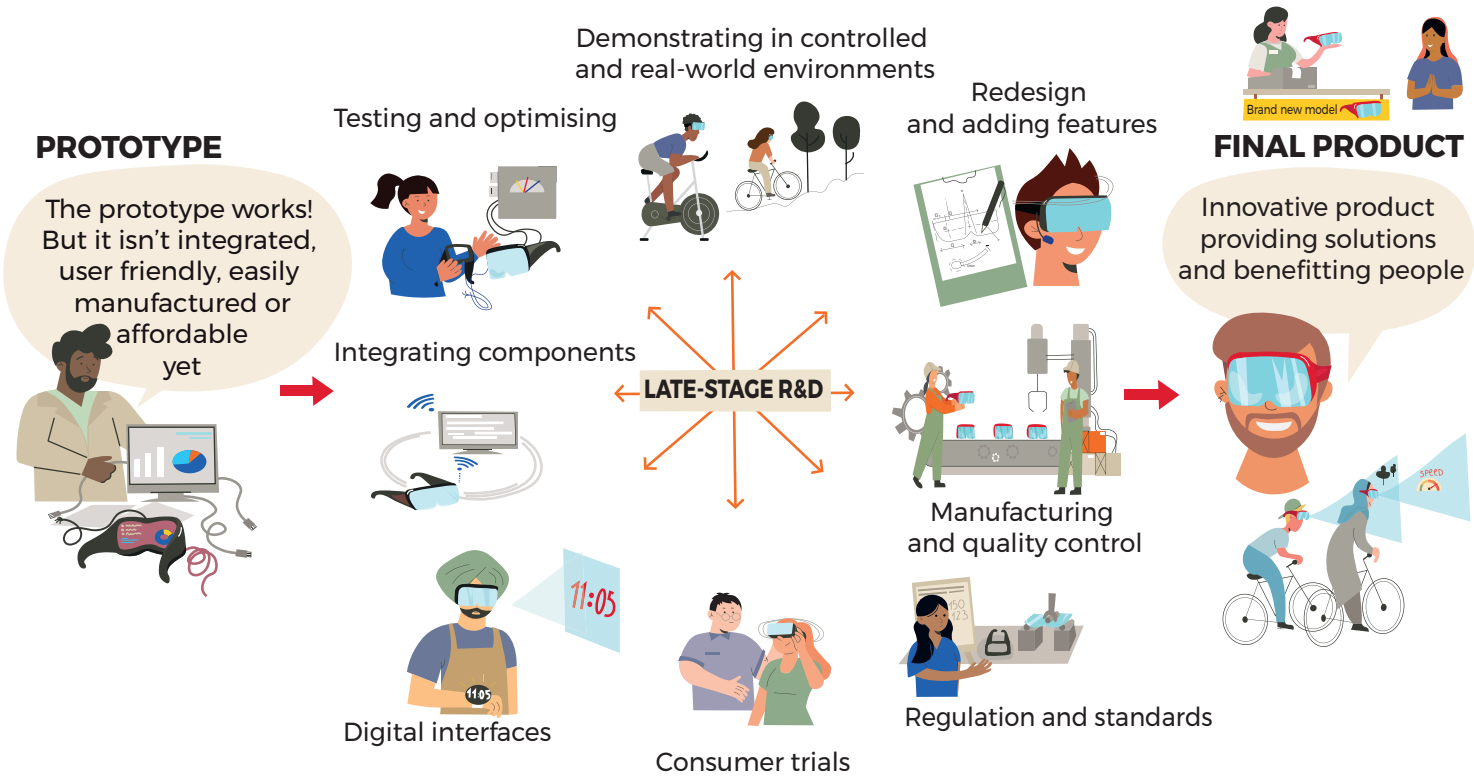
NATIONAL ENGINEERING POLICY CENTRE

Royal Academy of Engineering

Late-stage R&D: business perspectives

Late-stage R&D: from prototype to commercialisation



To fulfil its science superpower, innovation, growth and green industrial revolution ambitions, the UK government must make the UK a more attractive environment for businesses to invest and conduct late-stage R&D in.

Executive summary

What is late-stage R&D?

Late-stage R&D is a key part of the innovation process and accounts for the majority of R&D that businesses do. It comprises the activities required to take a proof of concept or prototype through to commercial application, ultimately delivering new products, processes, technologies and services to market.

Late-stage R&D delivers tradeable solutions and improvements, creates new markets and jobs, increases efficiency and improves productivity – bringing returns and socio-economic benefits to people in all parts of the UK. Late-stage R&D generates 'spill-over' benefits beyond the individual business, contributing to innovation and growth in the local area. It can act as a focal point for a business to develop activities and infrastructure, attract partners and investment, develop new local markets and establish a broader skills base around a particular location. Late-stage R&D is predominantly financed by businesses, with the private sector contributing approximately two thirds of the UK's investment in R&D.

Late-stage R&D, like all R&D and innovation carries risk. The risk is multifaceted, arising from the scale of the technical challenge, cost, timings, certainty of market opportunity, competitive environment and opportunities or barriers to commercialisation. There is a compelling case for the public sector to support businesses to manage the risks associated with late-stage R&D and incentivise business investment – the socio-economic benefits from the new products, processes, services and technologies are shared, so the risk must be too.

Late-stage R&D depends upon a thriving research base, involving universities, research institutes, R&D infrastructures, and businesses, to do the R&D required to provide a pipeline of projects ready to progress to late-stage R&D. Therefore, the health of the whole research and innovation system is crucial for successful late-stage R&D. However, this report focuses on support for late-stage R&D, an area identified as a UK weakness.[1]

Where are we now?

Many businesses choose global locations for these high value late-stage R&D activities, from multinationals with multiple R&D sites to mobile innovative SMEs with growth ambitions. But existing UK support for late-stage R&D is not meeting businesses' needs and is considered poor compared to competitor countries[2].

There is a choice to be made - enable companies to take bold risks here, or they will go elsewhere.

With severe pressures on public finances, the impact of the COVID-19 pandemic on businesses putting R&D investment at risk[3,4], and growing global competition, supporting businesses to manage the risks associated with late-stage R&D is a way of securing our future growth, as well as reaping the returns from our investment in research and delivering the government's ambitions for an innovation-led low-carbon economy. A focus on late-stage R&D will reap the returns from our investment in research, as long as the UK's research base continues to thrive.

Innovation will happen irrespective of the UK's policies; what is at risk is the UK's ability to drive and benefit from it.

How is late-stage R&D conducted and where can government play a role?

Understanding the activities that underpin late-stage R&D and the motivations, incentives, resources and barriers, including policy levers at government's disposal, will help identify what actions can be taken to ensure more late-stage R&D takes place in the UK. The report uses real-world examples to illustrate how different businesses conduct late-stage R&D, the range of activities and the resources they draw upon.

From interviews with engineering businesses, **five key common resources** essential for conducting and managing the risks associated with late-stage R&D were identified. Government can influence each of these resources to encourage business investment in late-stage R&D.

R&D infrastructures: the physical and digital infrastructures needed to test, certify and develop new products, processes, services and technologies safely and effectively.

Access to shared and world class public R&D infrastructures, as well as a cooperative and innovation-friendly regulatory and public sector environment, can support companies to demonstrate new products in use, helping generate investment and providing risk mitigation and certainty.

The UK should utilise infrastructure across the whole of the UK in a more creative way to test innovations, and also to support innovation more widely including through skills development, regulation and public engagement.

Investment: the availability of funds and fiscal measures that enable businesses to allocate funding for late-stage R&D activities.

It is appropriate that businesses assume significant financial risk for late-stage R&D, however due to significant 'spill-over' effects and global competition, there is a compelling case for government involvement. Furthermore, a substantial body of evidence has shown that public investment in R&D 'crowds-in' private investment.

Funding support for late-stage R&D is viewed as a gap, with fewer public funding opportunities than for the earlier stages of R&D. The UK is also a challenging environment to finance and raise private investment for late-stage R&D as investors often favour rapid returns and lower risk ventures. Government should develop new mechanisms targeted to help promising companies manage the financial risk associated with late-stage R&D and leverage business investment taking prototypes through to commercial application.

People: access and availability of diverse people with the experience and expertise to deliver technical and challenging projects to market.

Businesses will want to assemble the best team to deliver their R&D projects. Where large businesses may be able to invest and build their own pipeline of talent, sometimes in spite of government policy, that option is not open to all.

The UK talent pool and pipeline, from early age education through to vocational learning, higher education and lifelong adult learning, as well as visa conditions for international talent, must compete internationally to attract R&D from multinationals and SMEs into the UK. It must also meet the needs of UK SMEs to incentivise them to grow to scale in the UK.

Partnerships: the relationships, networks and collaborations that enable access to skills, infrastructure, investment and customers, reducing the burden placed on a single company through sharing resources and expertise with others.

Partnerships can provide game-changing opportunities for companies that lead to long-term growth in R&D investment in the UK.

Government has a key role in building partnerships, particularly through public R&D infrastructures. Government key role in building networks should be valued and incentivised by their KPIs. Government-initiated but industry-led activities and organisations, such as the Advanced Propulsion Centre and Aerospace Technology Institute, support strategic R&D partnerships reaching out across supply chains to innovate and respond to the challenges of the sector.

Market environment: the policies and frameworks influencing and producing opportunity or challenge for companies conducting late-stage R&D and commercialising innovation, including regulation, trade policy, intellectual property, and government strategies.

The ecosystem in which businesses conduct R&D is broad and complex. Government sets the tone and direction with strategies and policies that provide certainty and increased confidence for business and create greater opportunity for commercialisation.

To create a supportive environment for engineering business R&D and innovation, all government organisations must share a clearly defined vision of success and be well coordinated. This will provide a long-term stable backdrop for business decisions and investment.

A vision for 2027

In 2027, innovative and R&D intensive companies of all sizes are choosing to conduct R&D in the UK in preference to competitor countries. The UK is incentivising late-stage R&D and business investment with access to:

- a range of financial mechanisms and incentives targeted to late-stage R&D
- shared world-class R&D infrastructures for demonstration of new technologies
- a diverse and highly skilled workforce
- a multi-sector partnership ecosystem
- markets, both in the UK and globally through exports.

R&D and innovation underpin the UK's strategy for economic growth. There is a strategic approach across all government departments who work together to support business innovation and R&D, and to engage with businesses.

The policies and programmes to accelerate late-stage R&D have been co-designed by government and industry, with relevant government decision-makers having a deep understanding of the innovation system and businesses' experiences of interacting with it.

As a result, the UK's R&D drives the high-skill low-carbon economy, rather than simply delivering inventions for others to commercialise. This R&D gives the UK a strong competitive advantage, unleashing innovation, improving productivity, and delivering new products, processes, services and technologies that improve the lives of its citizens and solve society's challenges.

How to get there: recommendations to drive late-stage R&D in the UK

Late-stage R&D should lie at the heart of the UK government's Plan for Growth and upcoming Innovation Strategy.

Support should **target** late-stage R&D, with mechanisms that help businesses manage risk, filling gaps in current support.

- Government and industry should co-design new industry-led programmes, drawing on the successes of the Aerospace Technology Initiative (ATI) and Advanced Propulsion Centre (APC), to accelerate R&D in internationally competitive sectors and technologies that are vital to the delivery of national priorities such as net zero and infrastructure.

- The Department for Business, Energy and Industrial Strategy (BEIS), Innovate UK and the British Business Bank should work together to develop financial mechanisms designed to plug the gap in existing financial support for late-stage R&D (prototype to commercialisation, or Technology Readiness Levels 5 to 9).

Existing initiatives, institutions and infrastructures that support late-stage R&D should be **strengthened and scaled** to help businesses strengthen and scale their innovation activities and, in turn, their growth.

- Innovate UK should have an uplifted and multi-annual budget, with increased autonomy to design support mechanisms to rapidly meet the needs of innovative businesses, with longer-term tailored support as companies grow and more focus on de-risking and enabling late-stage R&D (for example, beyond prototyping).

- Government should promote and support strategic late-stage R&D and innovation infrastructures, such as the NPL and Catapult Centres, treating them as national innovation assets, with an uplift in public investment to enable them to step change their offer and engagement with innovative businesses and strengthen and scale their innovation ecosystems.

This improved and comprehensive package of support should be promoted globally to **signal** to the world that the UK is the place for businesses to come to undertake late-stage R&D and to unleash innovation.

- BEIS and UKRI should clearly signpost the UK's offer for late-stage R&D and innovation through an accessible online interface to facilitate navigation for the business user, and work with Department of International Trade to market it globally as part of a joined-up UK innovation pitch to international investors.

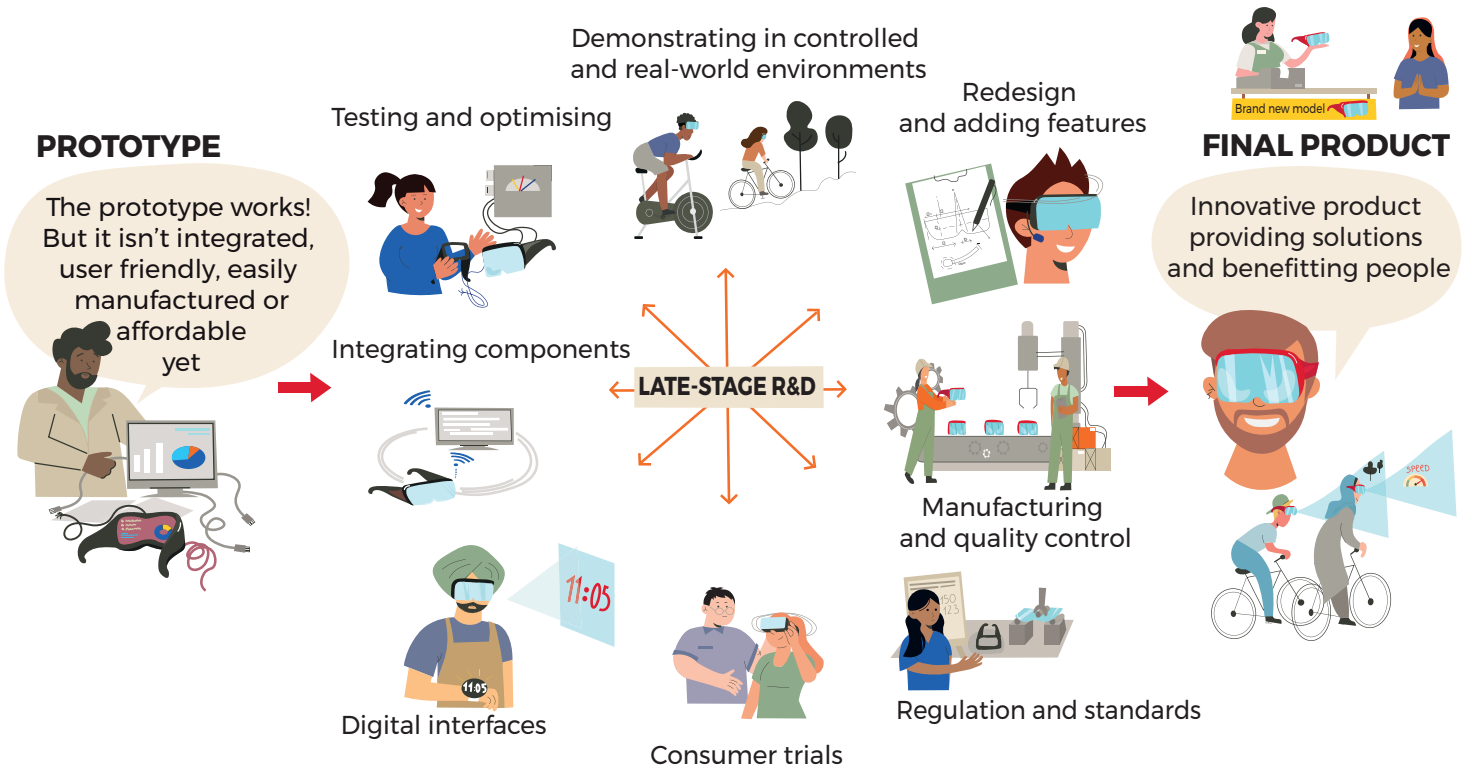
Introduction

What is late-stage R&D?

Late-stage R&D is a key part of the innovation process and accounts for the majority of R&D that businesses do. It comprises the activities required to take a proof of concept or prototype through to commercial application, ultimately delivering new products, processes, technologies and services to market. Examples of late-stage R&D as illustrated in the case studies throughout this report include:

- A new AI traffic monitoring system may need to be tested in a small town, to solve challenges that emerge from use in this real environment, before it can be rolled out for wider use.
  ▶Vivacity Labs case study
- An innovative optical technology may need to be integrated into a complex system to produce a headset for aircraft pilots and automotive drivers to see live information while driving.
  ▶BAE Systems case study
- A manufacturing process may need to be developed to produce a product, therapeutic or chemical in large quantities, efficiently in reasonable time and cost for commercial application.
  ▶Ventilator Challenge case study

Late-stage R&D: from prototype to commercialisation



Late-stage R&D delivers tradeable solutions and improvements, creates new markets and jobs, increases efficiency, and improves productivity – bringing returns and socio-economic benefits to people in all parts of the UK.

Late-stage R&D generates 'spill-over' benefits beyond the individual business, contributing to innovation and growth in the local area. It can act as a focal point for a business to develop activities and infrastructure, attract partners and investment, develop new local markets, and establish a broader skills base around a particular location.

Late-stage R&D, like all R&D and innovation, carries risk. The risk is multifaceted, arising from the scale of the technical challenge, cost, timings, certainty of market opportunity, competitive environment, and opportunities or barriers to commercialisation. There is a compelling case for the public sector to support businesses to manage the risks associated with late-stage R&D – the benefits from the new products, processes, services and technologies are shared, so the risk must be too.

Late-stage R&D depends upon a thriving research base, involving universities, research institutes, R&D infrastructures, and businesses, to do the R&D required to provide a pipeline of projects ready to progress to late-stage R&D. Therefore, the health of the whole research and innovation system is crucial for successful late-stage R&D. However, this report focuses on support for late-stage R&D, an area identified as a UK weakness[5].

Where are we now?

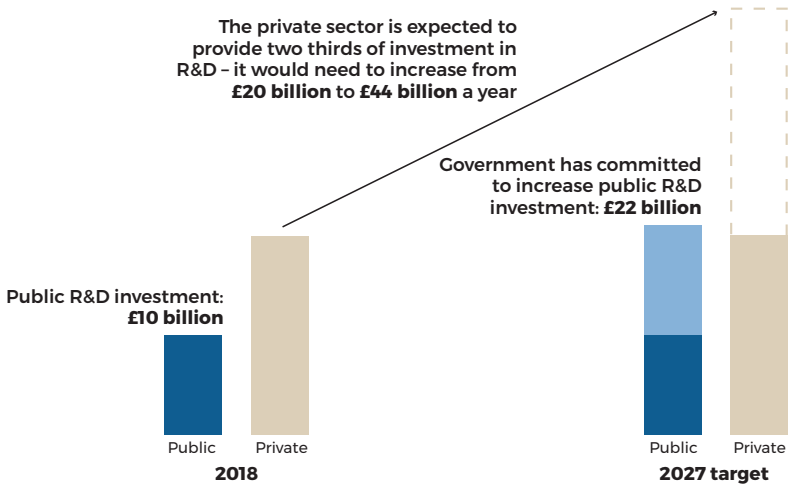
The UK government has committed to investing £22 billion in R&D by 2024–25 as part of a target of 2.4% of GDP by 2027, and 3% in the longer-term. Currently 1.7% of UK GDP is spent on R&D with the UK government investing £10 billion in 2018[6].

The private sector contributes approximately two thirds of the UK's R&D investment, and much of this will be for late-stage R&D. For UK industry to keep step with the government's promised increase in R&D investment, businesses will be expected to invest a lot more. The scale of the challenge should not be underestimated, especially in the context of COVID-19 and the new trade relationship with the European Union.

Beyond target numbers, this substantial increase in investment in R&D needs to deliver solutions, create jobs, and productivity, sustainability and socio-economic benefits all across the UK or risk missing the mark. Increasing late-stage R&D activities will be vital to achieving this.

Many businesses choose global locations for these high value late-stage R&D, from multinationals with multiple R&D sites to mobile innovative SMEs with growth ambitions. But existing UK support for late-stage R&D is not meeting businesses' needs and is considered poor compared to competitor countries[7].

Where are we now? Public and private investment in R&D and the 2027 target



There is a choice to be made – enable businesses to take bold risks here, or they will go elsewhere. With severe pressures on public finances and growing global competition, supporting businesses to manage the risks associated with late-stage R&D is a way to secure our future growth, as well as reaping the returns from our investment in research. Innovation will happen irrespective of the UK's policies; what is at risk is our ability to drive and benefit from it.

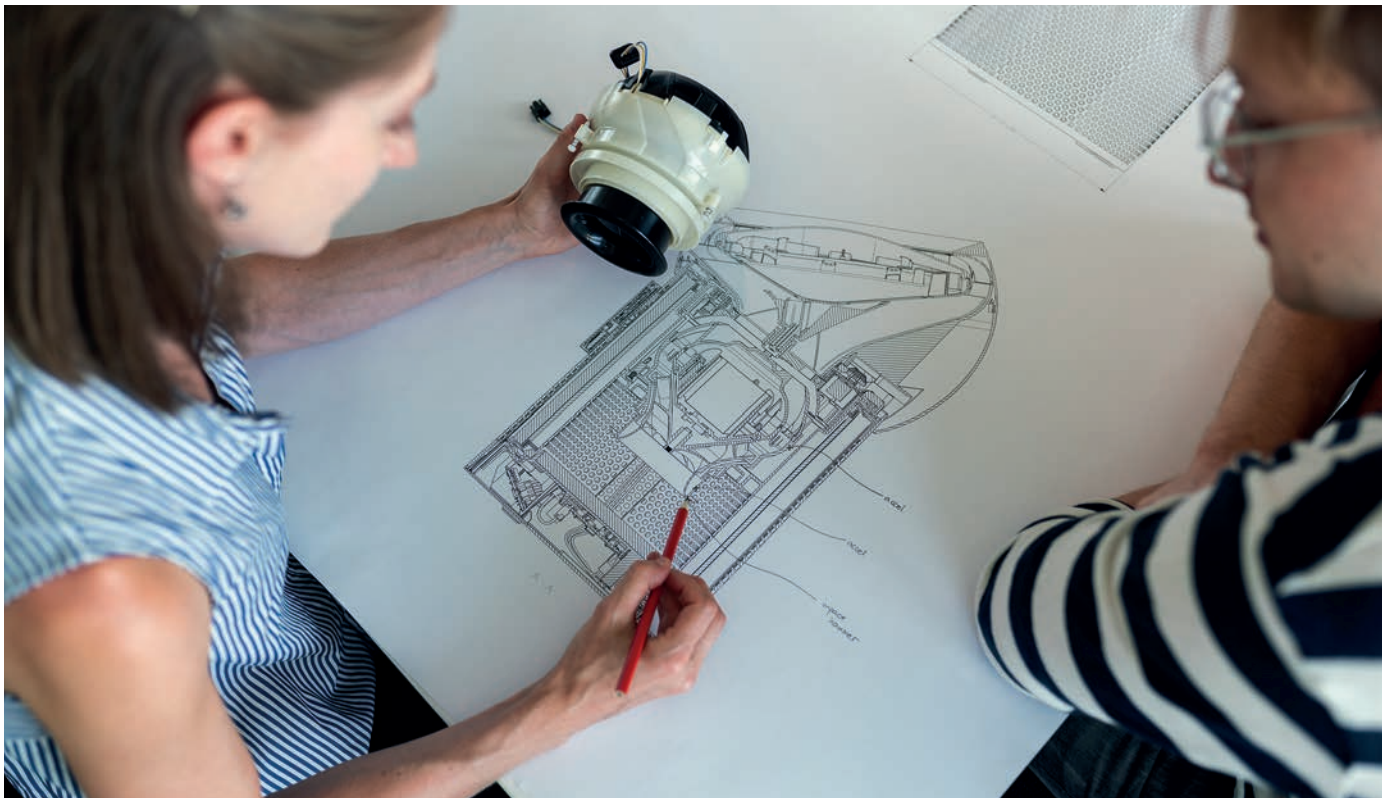
To fulfil its science superpower, innovation, growth and green industrial revolution ambitions, the UK government must make the UK a more attractive environment for businesses to invest and conduct late-stage R&D in.

The National Engineering Policy Centre interviewed the people responsible for business decisions about R&D at engineering businesses across a range of sectors, sizes and locations, to understand what is involved in undertaking late-stage R&D. Drawing on these experiences, this report illustrates:

A vision for 2027 and how to get there
What is late-stage R&D?
How is late-stage R&D conducted?

- R&D infrastructures
- Investment
- People
- Partnerships
- Market environment

Throughout the document real-life examples illustrate the realities of conducting late-stage R&D in the UK.



A vision for 2027

In 2027, innovative and R&D intensive businesses of all sizes are choosing to conduct R&D in the UK in preference to competitor countries. The UK is incentivising late-stage R&D and business investment with access to:

- a range of financial mechanisms and incentives targeted to late-stage R&D
- shared world-class R&D infrastructures for demonstration of new technologies
- a diverse and highly skilled workforce
- a multi-sector partnership ecosystem
- markets, both in the UK and globally through exports.

R&D and innovation underpin the UK's strategy for economic growth. There is a strategic approach across all government departments who work together to support business innovation and R&D, and to engage with businesses.

The policies and programmes to accelerate late-stage R&D have been co-designed by government and industry, with relevant government decision-makers having a deep understanding of the innovation system and businesses' experiences of interacting with it.

As a result, the UK's R&D drives the high-skill low-carbon economy, rather than simply delivering inventions for others to commercialise. This R&D gives the UK a strong competitive advantage, unleashing innovation, improving productivity, and delivering new products, processes, services, and technologies that support the economic recovery from COVID-19, improve the lives of its citizens and solve society's challenges.

How to get there

To achieve this vision, the government will need to place late-stage R&D at the heart of its Plan for Growth and upcoming Innovation Strategy as it increases its investment to £22 billion by 2024–25. Government will need to **target** support to late-stage R&D, with mechanisms that help businesses manage risk, filling gaps in current support. Existing initiatives, institutions and infrastructures that support late-stage R&D should be **strengthened and scaled**, which will help businesses strengthen and scale their innovation activities and, in turn, their growth. This improved and comprehensive package of support should be promoted globally to **signal** to the world that the UK is the place for businesses to come to undertake late-stage R&D and to unleash innovation.

Target

The competition to attract late-stage R&D activities is global, but existing UK support for late-stage R&D is not meeting businesses' needs[8]. Government should develop new mechanisms targeted to help promising businesses manage the financial risk associated with late-stage R&D – taking prototypes through to commercial application. The surest way to ensure these mechanisms hit the target is to co-design them with industry.

- **Government and industry should co-design new industry-led programmes to accelerate R&D in internationally competitive sectors and technologies** that are vital to the delivery of national priorities such as net zero and infrastructure. These should draw on the successes of the Aerospace Technology Initiative (ATI) and Advanced Propulsion Centre (APC), which take a strategic approach to support based on a clear analysis of the UK's sectors' needs.

- **BEIS, Innovate UK and the British Business Bank should work together to develop financial mechanisms designed to plug the gap in existing financial support for late-stage R&D** (prototype to commercialisation, or Technology Readiness Levels (TRL) 5 to 9). A range of support mechanisms will be needed to cater to the breadth of activities in late-stage R&D and the diversity of businesses involved. Consideration should be given to loans, convertible loans, prizes, equity investment, patient capital investment and means to leverage private investment. Schemes should be designed with the user in mind and widely promoted, with a clear point of contact for businesses seeking advice.

Strengthen and scale

From Innovate UK to the National Physical Laboratory (NPL) and Scottish Enterprise, the UK has strong initiatives, institutions and infrastructures that support late-stage R&D. However, over recent years lack of resources has limited their ability to meet the government's ambitions, preventing them from scaling their activities and in turn hampering businesses' abilities to scale. Given the limited resources available, government will maximise returns on previous investments by ensuring the continued operation of successful activities, rather than repeating the historic tendency towards scrapping and starting again. This will create a strong foundation from which innovation can accelerate.

- **Innovate UK should have an uplifted and multi-annual budget, with increased autonomy to design support mechanisms to rapidly meet the needs of innovative businesses**, with more of a focus on de-risking and enabling late-stage R&D (for example, beyond prototyping). This should include providing longer-term tailored support as businesses grow, schemes to support 'first of kind' demonstration activities and growth of non-financial support such as partnership building.

- **Government should promote and support strategic late-stage R&D and innovation infrastructures**, such as the NPL and Catapult Centres, treating them as national innovation assets, with an uplift in public investment. This will enable them to step change their offer and engagement with innovative businesses and strengthen and scale their innovation ecosystems.

Signal

The UK is outlining a bold, global vision for the UK as an outward-looking leading trading nation and a first-choice destination for inward investment and international talent. The UK's offer of support for late-stage R&D must be sold as part of that vision, both nationally and globally.

- **BEIS and UKRI should clearly signpost the UK's offer for late-stage R&D and innovation through an accessible online interface** to facilitate navigation for the business user, and work with Department of International Trade to market it globally as part of a joined-up UK innovation pitch to international investors.

What is late-stage R&D?

Late-stage R&D is what businesses do to take prototypes through to commercial application. It is the risk businesses must take to complete the activities to test, demonstrate and manufacture new products, services and processes with the aim of achieving commercial use and generating value, both social and economic, and staying competitive on the global stage. For example:

- A new autonomous machine learning software designed to detect and defend against cybersecurity threats may need 'early adopter' customers to provide a real-world environment to roll out the software, try out solutions and fix emerging problems before sales to a wider community
  ▶Darktrace case study

- Government support and backing for an international collaboration may be needed to take advantage of a new market opportunity for innovative small satellites, delivered to specification for disaster relief and building relationships through collaboration with commercial partners to generate orders for the next generation.
  ▶SSTL case study

- A new supply chain for electric car components may need to be built across the UK to compete in the growing global market.
  ▶McLaren case study

Late-stage R&D is iterative, non-linear and complex

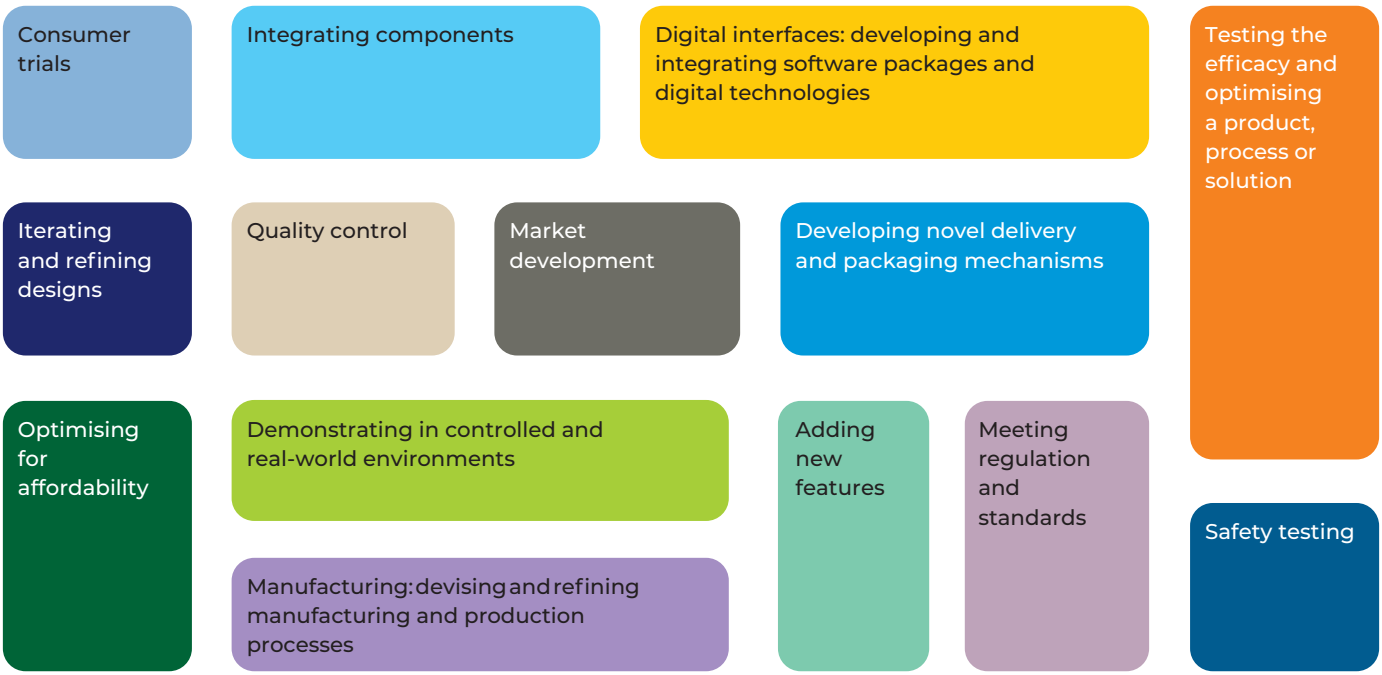
R&D activities may need to revisit earlier research or introduce feedback loops between different activities until a complete system can function in unison.

One size does not fit all

The scale and difficulty of challenges involved in late-stage R&D depend on the type of innovation, company size and the characteristics of the sector, with a direct impact on the time and cost of bringing a new product, process or service to commercial application.

- A software company may be able to rapidly develop innovative products in a few months but relies on access to skilled engineers and large datasets to test their products.

Late-stage R&D activities



- A manufacturing company may need several years and multi-million pound capital investment to build or adapt a manufacturing facility to bring a product to market.
- In the pharmaceuticals sector, the different stages to gain regulatory approval can take up to a decade.
- In construction, competition on contract costs, small profit margins and complex supply chains add challenges and barriers to late-stage R&D.

Encouraging late-stage R&D will take different forms and need different policy levers across different engineering sectors and beyond.

Late-stage R&D requires risk management

All R&D carries risk. For late-stage R&D the risk is multifaceted, arising from the scale of the technical challenge, cost, timings, certainty of market opportunity, competitive environment and opportunities or barriers to commercialisation. For businesses, the paramount risk is financial, with all other risk factors impacting the level of the financial risk. The balance of risk, and which parties carry that risk, changes over the lifetime of a R&D project.
▶What risk appetite do businesses have?

It is appropriate that businesses assume significant risk for late-stage R&D when they will be a major beneficiary. However, there are significant 'spillover' effects that mean that R&D creates substantial value for other businesses that adopt or adapt an innovation, as well as wider socio-economic benefits – thus there is a role for government.
▶What's the government's risk appetite.

"Between 2000 and 2008, innovation accounted for 51% of productivity growth[12]"

WHAT RISK APPETITE DO BUSINESSES HAVE?

Businesses risk appetite for R&D will vary significantly depending on the nature of the business and is affected by a diverse set of factors in the UK business environment. Individual businesses will have their own view of the risk conducting R&D carries for them, and which of these factors are most important, for example:

- Scale of technical challenge – is it an incremental or disruptive innovation? Does the company already have in-house expertise and know-how?
- Cost – what is the likely cost and how certain is that figure? Will there be costs associated with new plants and manufacture? Are the shareholders risk averse? Does the company have a history of investing in R&D? How do anticipated costs compare to the expected return on investment?
- Timings – how much time until revenue will be generated?
- Certainty of market opportunity – is there clear demand from customers? Is a first customer lined up? Is there a supply chain in place? Would it be creating a new market with associated risks such as new regulation?
- Competitive environment – is innovation a necessity to keep pace with competitors, or an expensive luxury in a low-innovation sector?

Businesses rarely engage in late-stage R&D if they are not certain they can deliver on the technical challenge – however the time needed to solve the challenge, the cost and the market potential are key drivers in the decision to embark on an R&D project. A large company in a competitive sector is driven to innovate to survive in the market, and therefore will quantify the risk of R&D, especially disruptive innovation, and weigh it against the risk of losing market share by standing still. A smaller company in a less innovative sector and with low profit margins may view the risk from the uncertainty in cost or market potential as much more significant and a greater barrier to overcome.

To incentivise companies to invest in R&D and innovation, it is vital to understand the environments that different businesses operate in, the policy levers that impact upon them and the questions that businesses ask themselves while considering whether, where and how much to invest in R&D.

Managing the risks associated with late-stage R&D is necessary for more of it to take place in the UK.

There is also a risk to not engaging in R&D and innovation: losing out to competitors.

Do definitions matter?

R&D, late-stage R&D and innovation mean different things to different people in different contexts. Standardised definitions matter for accounting, reporting and international comparisons and are based on the Organisation for Economic Cooperation and Development (OECD) *Frascati Manual* definitions of R&D and innovation. Late-stage R&D amounts to more than is captured in the Frascati definition of R&D, so an overly narrow focus on the Frascati definition of R&D risks failing to realise the full societal and economic benefits from R&D and innovation.

These definitions impact on the type of support governments are able to provide to businesses undertaking R&D and innovation activities and are linked to competition law and state aid. Definitions also impact on how businesses report their activities for accounting purposes, for example which activities are eligible for R&D tax reliefs.

These standardised definitions often do not reflect the terminology used by businesses, outside of financial reporting, nor do they capture the full range of activities required to realise the full societal and economic benefits from R&D and innovation[10]. Given there is no one-size-fits-all model for late-stage R&D and its variation by engineering sectors and across other disciplines, the language used also varies.
▶See What do engineering businesses say?

The aim of late-stage R&D is to produce tradeable products, processes and services, for the UK market and export.

Understanding the activities that underpin late-stage R&D – the motivations, incentives, facilities and barriers, as well as the policy levers at government's disposal – will help to establish what can be done to encourage more late-stage R&D in the UK.

WHAT'S THE GOVERNMENT'S RISK APPETITE?

As a nation the UK has a high-risk appetite when it comes to investing in research, even though the outcomes of research are extremely uncertain. This is demonstrated through the government's investment in the Research Councils (£2.68 billion in 2019/20[9]). It is accepted by government as a market failure.

As projects progress from research to development, the risk profile moves away from government and falls to businesses. The government's role shifts from directly taking the risk to sharing the risk with the businesses and helping them to manage it. Government support for sharing risk encompasses a wide range of policy levers, from direct grants to skills provision, to creating an enabling environment and infrastructure.

With a better understanding of the risks involved for businesses in late-stage R&D and greater appetite to share this risk, the UK government could pave the way to enable and ensure more businesses conduct these activities in the UK and deliver mutual benefit.

This is recognised by a range of other countries who are often able to offer a more attractive environment for companies wishing to undertake this type of R&D.

WHAT DO ENGINEERING BUSINESSES SAY?

Outside of accounting purposes, businesses use a range different terminology for their R&D activities, meaning different things to different companies. From the interviews conducted for this project, businesses describe their R&D activities as:

- Development, demonstration and deployment.
- Research, development and commercialisation.
- R&D for TRLs 1–4 and innovation for TRLs 5–9.
- Research and technology development up to TRL 6 then commercialisation.
- Innovation for TRLs 1–5 then product development and scaling for TRLs 5–9.

Underlying these terms are all the activities that businesses do to take their prototype through to full commercial application..

FRASCATI/FORMAL DEFINITIONS

R&D is defined in the *Frascati Manual*[11] as 'creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge" and includes basic research, applied research and experimental development.

Innovation often draws on R&D, but R&D is not always part of the activity of innovation. "An innovation is defined as the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations."

There is subjectivity with capturing R&D or wider innovation process, as acknowledged by the Frascati Manual: "it is difficult to define precisely the cut-off point between experimental development and preproduction development; the distinction between the two requires 'engineering judgement' as to when the element of novelty ceases and the work changes to routine development of an integrated system."

START-UPS: A DIFFERENT APPROACH TO RISK

High-tech innovative startups often have a greater risk appetite compared to more established businesses. By their very nature, innovative startups manage high levels of risk as their success often entirely depends on bringing a new product, process, service or technology to market and undertaking late-stage R&D. For innovative startups, investing in late-stage R&D is the only option.

"An extra £1 of public R&D funding stimulates £0.41 to £0.74 private R&D investment in the same year and between £1.96 and £2.34 of private R&D after five to 15 years[13]"

TECHNOLOGY READINESS LEVELS

Technology Readiness Levels (TRLs) is a commonly used framework to assess the maturity of technologies and was developed by NASA in 1970s. There is no single way to define TRLs and various classifications have been formulated to serve different needs, sectors and organisations. TRLs have been widely adopted for use in other sectors beyond space technology. Where sectors do not use TRLs the steps tend to still be recognisable to their R&D and innovation processes. While TRLs have well-known limitations, they can be helpful tool in guiding discussions and benchmarking experiences.

Late-stage R&D covers TRL 5–9. Businesses conduct R&D across the TRL scale, covering research, often in partnership with universities, early development and late-stage development where late-stage is the majority.

There are variations on the theme of TRLs that permit a greater focus on different aspects of readiness, for example systems readiness levels (SRLs) to represent the readiness of the system of technologies (or even system of systems) and manufacturing readiness levels (MRLs) which assess whether the technology is ready to go into production.

TRL 1
Basic research. Principles postulated and observed but no experimental proof available.

TRL 2
Technological formulation. Concept and application have been formulated.

TRL 3
Applied research. First laboratory tests completed; proof of concept.

TRL 4
Small scale prototype built in a laboratory environment ('ugly' prototype).

TRL 5
Large scale prototype tested in intended environment.

TRL 6
Prototype system tested in intended environment close to expected performance.

TRL7
Demonstration system operating in operational environment at pre-commercial scale.

TRL 8
First of a kind of commercial system. Manufacturing issues solved.

TRL 9
Full commercial application, technology available for consumers.

How is late-stage R&D conducted?

The people at the centre of businesses' decisions around R&D are chief technology officers, chief engineers, and in some businesses, chief executives. They are the ones that make the case for R&D within the business and deliver the R&D, including where and how it is done, managing the multifaceted risks involved daily. The decisions they make are complex and sensitive to the individual nature of the company.

Understanding the activities that underpin late-stage R&D and the motivations, incentives, resources and barriers, including policy levers at government's disposal, will help identify what actions can be taken to ensure more late-stage R&D takes place in the UK.

The National Engineering Policy Centre has spoken to the people responsible for R&D at 32 engineering businesses across a range of sectors, sizes and locations. Based on these recent real examples, this report showcases how businesses conduct late-stage R&D and highlights some of the key factors that they have to consider.

- **BAE Systems**: commercialising a disruptive innovative product with opportunities across different markets ▶See case study
- **CCm Technologies**: grants supporting the development of carbon capture, utilisation and resource optimisation technology ▶See case study
- **Darktrace**: customers with an appetite for innovation to demonstrate new AI products ▶See case study
- **Project ESCAPE**: building a UK supply chain for electric car components to compete in a growing market ▶See case study
- **ITM Power**: working with regulators to safely roll out new hydrogen refuelling stations ▶See case study
- **Qinetiq**: testing an autonomous land vehicle in live exercises with the British Army ▶See case study
- **Siemens**: living labs for the integrated energy systems of the future ▶See case study
- **Spirit AeroSystems Belfast (previously Bombardier)**: developing an award-winning aircraft wing and sustaining high-value jobs with loan and grant support from government ▶See case study
- **Surrey Satellite Technology Ltd:** bringing government in to grasp an opportunity with small satellites ▶See case study
- **Unipart Manufacturing**: from conducting no R&D to a joint venture with Coventry University ▶See case study
- **Ventilator Challenge UK**: assembling the skills to deliver ventilators to the NHS in record time ▶See case study
- **Vivacity Labs**: developing an AI traffic management system on the streets of Milton Keynes and Manchester ▶See case study

Despite the diversity of approaches and activities involved in late-stage R&D, discussions with businesses identified five key common resources essential for conducting and managing the risks associated with late-stage R&D:

R&D infrastructures: the physical and digital infrastructures needed to test, certify and develop new products, processes, services and technologies safely and effectively.

Investment: the availability of funds and fiscal measures that enable businesses to allocate funding for late-stage R&D activities.

People: access and availability of diverse people with the experience and expertise to deliver technical and challenging projects to market.

Partnerships: the relationships, networks and collaborations that enable access to skills, infrastructure, investment and customers, reducing the burden placed on a single company through sharing resources and expertise with others.

Late-stage R&D does not happen in a vacuum. The market environment in which businesses and customers operate affects access to the resources needed for R&D, as well as the appetite to commercialise and buy innovation, and the wider non-R&D interests of businesses.

Market environment: the policies and frameworks influencing and producing opportunity or challenge for businesses conducting late-stage R&D and commercialising innovation, including regulation, trade policy, intellectual property, and government strategies.

These five key common resources are intrinsically interdependent. These resources affect a company's ability to undertake late-stage R&D by helping to manage risk including solving technical challenges, the timescales involved and ultimately the potential success of commercialisation. As such, a company weighs up the availability and quality of these resources when considering:

- whether it should undertake late-stage R&D, and
- where late-stage R&D activities should be carried out.

Government can influence the quality and availability of these resources through the wide range of policy levers at its disposal.

Government policy levers that impact late-stage R&D

R&D infrastructures

The physical and digital infrastructures needed to test, certify and develop new products, processes, services and technologies safely and effectively

Public R&D infrastructures, their availability, accessibility and strategic focus

Regulators and their openness and availabilty to engage in innovation

Data for development and its accessibility

Finance, planning rules and processes to build new R&D infrastructures

Local government and public sector organisations such as the NHS, accessibility and engagement in test beds and living labs

Physical and digital R&D infrastructures are used by businesses to undertake a wide range of late-stage R&D activities to accelerate the development of a new product, technology, service or process[14,15,16].
R&D infrastructures are used to:

- **test new products in use in real environments**, for example testing an AI traffic monitoring system in the streets of Milton Keynes.
  ▶Vivacity Labs

- **solve technical challenges, including manufacturing at commercial scale**, for example accessing and developing the manufacturing line to increase production volume from 60 to over 1000 ventilators per week.
  ▶Ventilator Challenge UK

- **meet regulatory requirements**, for example validating a new transformer for safe and reliable use before integrating it into the electric grid.

- **demonstrate an innovative solution to potential customers**, for example building a first hydrogen refuelling station in the UK and proving a roll-out model attracting investment from a leading global engineering company.
  ▶ITM Power

R&D infrastructure can be internal to the business, or a shared external facility, such as public facilities like the National Physical Laboratory or the Catapult Centres, or private, for example incubators or specialist testing facilities. In some cases, establishing new R&D infrastructures is part of the late-stage R&D process, for example building a new energy demonstrator plant or a new manufacturing centre.
Shared R&D infrastructure plays a crucial enabling role by providing:

- **access to specialist equipment, knowledge, data that would otherwise be unaffordable or inaccessible to companies**

- **engagement with real users, regulators, local authorities or potential customers.**

R&D infrastructures

Without access to R&D infrastructures, and more importantly certainty of access, the risk of conducting late-stage R&D increases rapidly for businesses with the introduction of delays or additional cost in securing the right skills and facilities. Challenges in accessing existing R&D infrastructures include: time delays; lack of awareness or prohibitive costs; the absence of needed R&D infrastructures; and the costs associated with building new infrastructures, which can be insurmountable barriers to pursuing late-stage R&D. Conversely, the availability of R&D infrastructures can provide a huge draw for companies within and beyond the UK, especially if they offer unique expertise and capabilities.

Where can the UK government play a role?

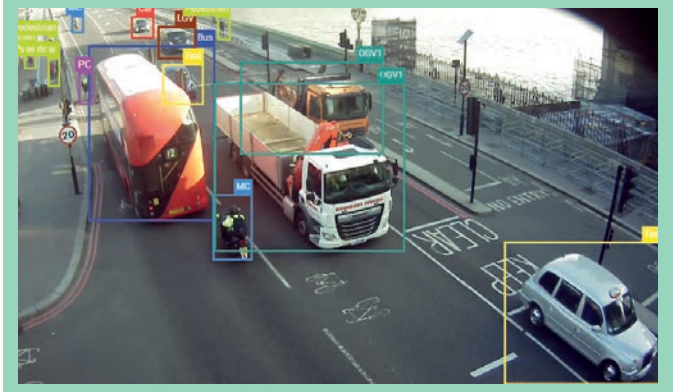
Access to shared and world class public R&D infrastructures, as well as a cooperative and innovation-friendly regulatory and public sector environment, can support companies to demonstrate new products in use, helping generate investment and providing risk mitigation and certainty.

The government should utilise infrastructure more creatively across the whole of the UK to test innovations, but also to support innovation more widely including through skills development, regulation and public engagement.

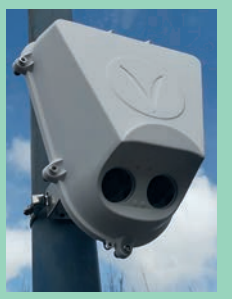
For public R&D infrastructures, the government should promote and support strategic late-stage R&D and innovation infrastructure, such as the NPL and Catapult Centres, treating them as national innovation assets, with an uplift in public investment to enable them to step change their offer and engagement with innovative businesses and strengthen and scale their innovation ecosystems.

CASE STUDY

VIVACITY LABS: DEVELOPING AN AI TRAFFIC MANAGEMENT SYSTEM ON THE STREETS OF MILTON KEYNES AND MANCHESTER



Photos used with permission from Vivacity Labs



Vivacity Labs is a London-based startup that combines artificial intelligence (AI) and the Internet-of-Things to improve transport networks. With Innovate UK funding, it opened a first-of-a-kind manufacturing facility in Bletchley in 2017 to build, test and produce sensors. These sensors were then deployed in a real-world environment, across Milton Keynes, where they delivered up-to-the-minute city-wide transport data as well as a testbed for further AI development. Following this demonstration project, Vivacity Labs have won contracts with multiple clients both in the UK and internationally.

Its current focus is in developing an artificial intelligence traffic light optimisation system in a living lab in Manchester where they are now managing traffic lights in the real world and already demonstrating 30% reductions in traffic delays compared to existing systems. The company adapted its technology to help anonymously analyse social distancing behaviour for the Department for Transport in response to COVID-19.

R&D infrastructures

CASE STUDY

SIEMENS: LIVING LABS FOR THE INTEGRATED ENERGY SYSTEMS OF THE FUTURE

Photo © Tyseley Energy Park

Siemens is developing new technologies and services for future global distributed energy systems. Siemens has found that the use of living laboratories can offer opportunities to evaluate new business models, customer acceptance in real environments and accelerate their market introduction. Siemens has a number of collaborations across Europe, including: Aspern, Vienna; Project Triangulum in Manchester; and Project Ruggedised in Glasgow.

More recently, Siemens has started to partner with several UK universities to test technologies across their campuses, facilities and student accommodation, while supporting them to reduce energy costs and carbon footprint. The data and learning from the projects are also being shared with the universities for use in teaching. Deploying the technology in different types of accommodation, new and old, that is representative of the housing stock is essential to developing a technology that can work globally.

"The High Value Manufacturing Catapult supported 4,646 innovation projects in 2019/2020 across its seventeen locations[25] and £518 million of industry R&D was linked to catapult activity."

MANUFACTURING AT SCALE

Producing a novel product at scale, efficiently and reliably is the next challenge after producing prototypes in a laboratory. ▶Ventilator Challenge UK. **Manufacturing processes may need to be developed or require custom and specialist machinery**.

Centres such as the Cell and Gene Therapy Catapult, High Value Manufacturing Catapult or the Offshore Renewable Energy Catapult provide access to specialist equipment and expertise for companies to develop and validate processes before investing in new costly equipment or manufacturing facilities themselves[23,24]. This shared infrastructure supports risk management by providing a venue and supportive expertise to try out innovative processes before investing the full cost of new equipment.

MEETING SAFETY, REGULATORY NORMS AND STANDARDS

Regulatory procedures, including access to specialist testing facilities may be required to certify safety and reliability norms and standards. In the case of highly innovative products, the time to develop new regulation can introduce delay or uncertainty during the product development ▶ITM Power.

R&D infrastructures

CASE STUDY

ITM POWER: WORKING WITH REGULATORS TO SAFELY ROLL OUT NEW HYDROGEN REFUELLING STATIONS

Photo used with permission from ITM Power

ITM Power is a Sheffield-based company manufacturing electrolysers for enabling green hydrogen solutions, including fuel stations for zero emissions transport. ITM built its first prototype hydrogen refuelling station in 2007, and the first public facing station in 2014 with support from the UK government's Hydrogen Transport Fund.

ITM Power worked closely with local authorities, BCGA, the Energy Institute and Ofgem to develop a code of practice for deploying this new technology. With a proven roll out model, ITM Power has since built ten more public-facing stations in the UK, Europe and North America. The first station helped put them on the radar of Linde, a global engineering company that has since acquired a minority stake and established a joint venture to deploy large-scale electrolysers in industrial processes.

Solving the great global challenges: net zero

Achieving a thriving, low-carbon economy and reaching the 2050 net-zero target will involve rapid, co-ordinated and large-scale systemic change. Deployment and integration of existing low-carbon technologies, combined with ongoing innovation, could position the UK as a market leader.

Delivering on the UK's ambitious climate change goals will require investing in large-scale late-stage R&D projects to deploy, at scale, all credible known and developing clean technologies.

As outlined in the Prime Minister's *Ten point plan for a green industrial revolution*[28], there is a real opportunity to harness, leading the world by example and developing, demonstrating and commercialising the technologies necessary to respond to the climate crisis.

REAL-WORLD ENVIRONMENTS FOR REGULATED TESTING

Test beds, living labs and regulatory sandboxes provide real world conditions, physical or digital, for new products to be tested and demonstrated in use with real customers ▶Siemens, ▶Vivacity Labs[17,18,19,20]. They bring together the public and private sector and provide:

- **Safe spaces to conduct live experiments** and maximise performance and benefits from new products and technologies.
- **Collaboration**, with for example:
  - **Real users** engaging with the new product to highlight any problems that might emerge.
  - **Engagement on regulation**[21,22] helping companies understand regulatory considerations, potentially reducing time to market and helping regulators ensure their frameworks are fit for the future.

R&D infrastructures

CLINICAL TRIALS

In the pharmaceutical and biomedical engineering sector, clinical trials[27] are a crucial step prior to regulatory approval, licensing and commercialisation of new medical devices, therapeutics and vaccines. They:

- **demonstrate safety** and identify potential side effects
- **validate effectiveness** in treating a condition.

These often last several years, involve the regulator and healthcare organisations and large numbers of people, sometimes across different countries.

"The National Physical Laboratory supports UK industry with the latest advances in measurement science and technology to gain a competitive edge. For one SME, Anglia CNC Engineering, the product verification work they conducted with NPL has resulted in more than £50,000 in savings per year[26]"

FIRST OF A KIND AND DEMONSTRATORS

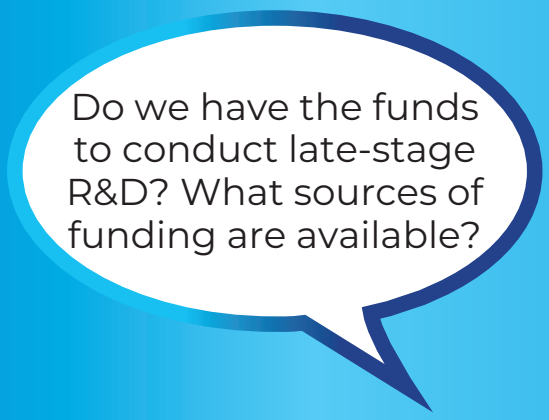
'First of a kind' is a term often used in the context of infrastructure projects or large-scale manufacturing. An innovative first will often need to be built with a degree of uncertainty remaining and the associated risk can be a barrier to private investment.

The first of a kind validates the performance or potential of the technology, providing reassurance and interest from investors. It is also an opportunity to **learn lessons to improve the efficiency of subsequent builds**. In some sectors, such as the energy sector, a first of its kind may also require close involvement of regulators to ensure safety. ▶ITM Power.

Public sector backing for this type of R&D infrastructure is often essential due to the regulatory element, high cost and risk associated to the investment.

Investment

The availability of funds and fiscal measures that enable businesses to allocate funding for late-stage R&D activities



Public funding, including grants and loans for late-stage R&D

Public procurement and government as a customer to pull through and scale up late-stage R&D

Fiscal incentives including R&D tax reliefs

Private markets and investment incentives

To conduct late-stage R&D, businesses require funds to cover the various costs involved, such as materials, workforce and infrastructure. Given that outcomes and duration of late-stage R&D activities can be uncertain, conducting late-stage R&D carries a financial risk and the financial impact is often perceived by businesses as the **greatest risk to manage**.

"Companies reported cost as the biggest barrier to conducting R&D in the UK Innovation Survey 2019[29]"

Companies finance late-stage R&D in a range of ways.

Businesses generally finance R&D with a portion of their profits, and as such, their ability to invest in R&D is a function of the current business environment. However, businesses often seek external sources of finance to support late-stage R&D, with multiple sources potentially used throughout the duration of a late-stage R&D project. For example, CCm Technologies has funded its R&D activities with a combination of grants from BEIS and Innovate UK, EIS equity and have scaled to a position to win commercial contracts.

External sources of investment include:

- Grants for R&D and innovation from public bodies such as Innovate UK, EU Research and Innovation programmes, Scottish Enterprise, Invest Northern Ireland.
- Commercial loans from banks.
- Government loans, for example the loans Spirit Aerosystems Belfast (previously Bombardier) and

Investment

SSTL agreed with government after identifying a commercial opportunity that they could otherwise not have pursued.

- Private markets such as private equity and venture capital.
- Capital markets such as the London Stock Exchange for publicly listed companies.
- Joint investment through partnerships or a consortium of companies.
- Contracts from customers, including from government.
- Innovation funds or allowances for regulated or government owned enterprises.

Company culture, ownership and structures have a huge influence on appetite for risk-taking with investment in R&D.

R&D investment decisions are complex and take into account a range of factors, including company finances, market trends, opportunities, threats and other priorities. The decision and scale of investment in R&D is often decided at the company board level. The risk appetite of the board, shareholder attitudes and expectations of returns, or whether a business is privately owned or public can both drive or act as a barrier to investment in R&D. For example:

- Businesses with small margins or startups with insecure sources of revenue are less able to pursue a strategic long-term approach due to the need to secure cash flow.

- To manage risk, many businesses pursue R&D activities only if they have secured a grant or contract to deliver and with a shorter turnaround between 18 months and three years.

- Larger businesses often operate a portfolio model with projects across different timescales, cost and challenge. However, even within larger corporates there can be competition between different business units to release funds for R&D.

How much does late-stage R&D cost?

The costs increase as the projects approach market, with the number of staff involved and scale of infrastructure likely increasing as the project progresses to include the broader skills and facilities needed. However, the costs vary significantly across sectors and the type of R&D and innovation, for example:

- New-to-market disruptive innovation can take a decade to develop and requires significant infrastructure investment such as a new manufacturing plant or innovative power plant design, and additional time for regulatory approval, for example in the pharmaceutical sector. In this case, the cost of late-stage R&D can reach tens or hundreds of millions.

- Shorter R&D projects, available for commercial use within 18 months to three years, can be significantly cheaper.

- Where the cost of R&D is limited to staff costs, the time to reach market can be very quick, for example with digital technology, late-stage R&D is much cheaper than in other engineering sectors.

PUBLIC FUNDING FOR LATE-STAGE R&D

The UK has historically under-invested in innovation and the 'D' of R&D[31,32]. UKRI had a £7.4 billion budget in 2019/2020, of which £2.68 billion was allocated through the Research Councils, generally on projects covering research and early development[33]. In contrast, Innovate UK, focused more towards development and demonstration, had a budget of £1.3 billion, including $491 million for the Industrial Strategy Challenge Fund.

"Corporate incentives in the FTSE 350 inhibit innovation[30]"

Investment

Where can the UK government play a role?

It is appropriate that businesses assume significant financial risk for late-stage R&D, however due to significant 'spillover' effects and global competition there is a compelling case for government involvement. Furthermore, a substantial body of evidence has shown that public investment in R&D 'crowds-in' private investment.

Funding support for late-stage R&D is viewed as a gap, with fewer public funding opportunities than for the earlier stages of R&D. The UK is also a challenging environment for financing and raising private investment for late-stage R&D as investors often favour rapid returns and lower risk ventures. Government should develop new mechanisms targeted to help promising companies manage the financial risk associated with late-stage R&D – taking prototypes through to commercial application.

Innovate UK should have an uplifted and multi-annual budget, with increased autonomy to design support mechanisms to rapidly meet the needs of innovative businesses, with more of a focus on de-risking and enabling late-stage R&D (for example, beyond prototyping). This should include providing longer-term tailored support as companies grow, schemes to support 'first of kind' demonstration activities and growth of non-financial support such as partnership building.

BEIS, Innovate UK and the British Business Bank should work together to develop financial mechanisms designed to plug the gap in existing financial support for late-stage R&D (prototype to commercialisation, or TRL 5 to 9). A range of support mechanisms will be needed to cater to the breadth of activities in late-stage R&D and diversity of companies. Consideration should be given to loans, convertible loans, prizes, equity investment, patient capital investment and means to leverage private investment.

CASE STUDY

SPIRIT AEROSYSTEMS BELFAST (PREVIOUSLY BOMBARDIER): DEVELOPING AN AWARD-WINNING AIRCRAFT WING AND SUSTAINING HIGH-VALUE JOBS WITH LOAN AND GRANT SUPPORT FROM GOVERNMENT

Photo used with permission from Spirit Aerosystems

In 2006, Bombardier saw an opportunity to develop the only purpose-built aircraft for the 100 to 150 seat market. The aircraft, which entered service in 2016, became the Airbus A220 in 2018. Bombardier Belfast developed the aircraft wing using advanced composites to reduce weight by 10% compared to a metallic wing and improve corrosion resistance for greater efficiency and easier maintenance. Bombardier secured a £100 million loan from the UK government and £20 million in grants from Invest NI and, in total, invested more than £520 million in the development of the new product. This included a purpose-built 600,000 square foot facility in Belfast to house wing production, from receipt of raw material right through to despatch of assembled product.

Spirit AeroSystems recently acquired Bombardier's Belfast operation to diversify and strengthen its portfolio, including the addition of the composite wing programme for the Airbus A220 aircraft family. Looking towards the recovery of the aviation industry following the impacts of the global pandemic, Spirit has long-term plans to expand its Belfast wing manufacturing and assembly facility to accommodate future ramp-up activity on the programme, which will support jobs both within Spirit and its supply chain.

Investment

CASE STUDY

CCm TECHNOLOGIES: GRANTS SUPPORTING THE DEVELOPMENT OF CARBON CAPTURE, UTILISATION AND RESOURCE OPTIMISATION TECHNOLOGY

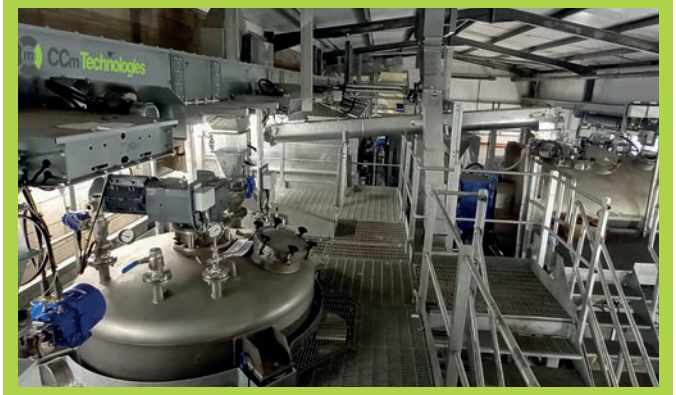


Photo used with permission from CCm Technology

CCm Technologies has developed a carbon utilisation technology – capturing carbon dioxide and waste streams to be converted into materials for use in fertilisers, plastics and energy storage. It started in 2012 and are now reaching scale-ready commercialisation. The development of the technology has been funded through Enterprise Investment Scheme equity and grants from the UK and Canada.

In 2020, CCm Technologies, in partnership with Severn Trent, won £1 million from BEIS and the Carbon Trust to develop a waste-water recycling process using captured CO2 to stabilise nitrogen, phosphate and organic chemicals held within waste streams at Severn Trent, turning them into sustainable plant nutrients.

Access to grant funding has enabled CCm Technologies to develop the technology, tailor a product for interested customers and infill various aspects of the technology as it prepares to move to commercial contracts. Non-financial support from Innovate UK was also hugely valuable, with support to create exhaustive financial models and a four-minute video building credibility with large organisations and good communication of complex engineering solutions. In July 2020, CCm announced a commercial contract with Yorkshire Water to recovery nutrients, primarily ammonia and phosphorus, from effluent discharge.

CASE STUDY

SURREY SATELLITE TECHNOLOGY LTD: BRINGING GOVERNMENT IN TO GRASP AN OPPORTUNITY WITH SMALL SATELLITES

Photo © ISRO/Antrix

Surrey Satellite Technology Ltd (SSTL) identified a market opportunity for small satellites in Earth observation. It proposed a constellation of affordable microsatellites to provide timely images and information supporting disaster relief, not readily available from large satellites. The UK government agreed to support the project with funding to catalyse an international consortium across six countries to collaborate on building a constellation of six optical Earth observation microsatellites. Working with users to help define image specification for disaster relief was crucial, enabling SSTL to clarify key basic needs to bring the cost and size of the satellites down to something achievable while still delivering useful information. From idea to delivery in orbit took five years.

Commercially, the project was a huge success and allowed SSTL to build six satellites and receive export orders for the next generation satellites from the partner countries. It helped expand its market and build long term relationships with international partners, raising the visibility of the UK space community internationally.

People

The access and availability of diverse people with the experience and expertise to deliver technical and challenging projects to market

Can we access the skilled workforce to do late-stage R&D in the UK?

Education policy delivering a skilled and diverse workforce

Immigration policy including cost and processes to hire international talent

Knowledge exchange and ease of access to the UK's excellent research base

A clear path to access the necessary people is key to a business's management of the risk of R&D[34]. For multinational or mobile businesses, the ability to access the right people for a project, whether internally through training or through hiring nationally or internationally, will in part drive the decision on where to locate R&D activities.

"The UK Innovation Survey 2019 found that 38% of UK businesses were innovation active, down from 49%[35] in 2016–18. Lack of qualified personnel was one of the barriers cited"

Late-stage R&D draws upon a wide range of skills

The skills for late-stage R&D can be broadly grouped into technical and non-technical[36,37]:

- **Technical**: from the apprentice to the technician, mid-career engineer and chief technology officer, late-stage R&D draws on specific technical expertise relevant to the project, and wider engineering experience and problem solving are essential to progress development.
- **Non-technical**: management, risk analysis and finance, marketing, creative and design skills support the smooth delivery of late-stage R&D projects to commercialisation.

Both technical and non-technical skills are needed for any late-stage R&D project, for example, bringing together digitalisation technologies with medical technology and regulatory expertise, manufacturing, fast-paced problem solving, logistics and accountancy to smoothly deliver an upscaling of ventilator production. ▶Ventilator challenge UK

People

An international and diverse workforce

International diversity is strongly valued by many organisations, including specifically for R&D[38]. Businesses actively seek R&D staff from across the world, to provide the skills needed and to benefit from diversity[39]. Diversity in teams provides cultural understanding, language skills, and a diverse source of ideas, facilitating the development of goods and services for a global market. UK immigration, education policy and skills availability influence businesses' decisions to locate late-stage R&D activities in the UK.

Absorptive capacity

Businesses need to have the capacity to absorb external knowledge and develop internal skills and talent. This absorptive capacity is linked to a business' ability to adapt to technical change and innovate[44,45]. In return, conducting R&D supports the development of skills and know-how within an organisation to be more competitive and innovative. Small innovative businesses may have more unbounded absorptive capacity and potential for growth, which can benefit innovation across the broader sector and supply chains through collaborative partnerships.

Even if a late-stage R&D project does not result in a successful commercial outcome, the business will have acquired valuable new experience, skills and expertise.

Where can the UK government play a role?

Businesses will want to assemble the best team to deliver their R&D projects. While large businesses may be able to invest and build their own pipeline of talent, sometimes in spite of government policy, that option is not open to all.

The UK talent pool and pipeline, from early age education through to vocational learning, higher education and lifelong adult learning, as well as visa conditions for international talent, must compete internationally to attract R&D from multinationals and SMEs into the UK. It must also meet the needs of UK SMEs to incentivise them to grow to scale in the UK.

"Diverse and inclusive workspaces promote innovation and financial performance[40,41,42]. Companies with higher-than-average total diversity were found to have 19% higher innovation revenues[43]"

INNOVATION, THE PRODUCTIVITY PUZZLE AND JOBS

UK productivity growth has been effectively non-existent since 2008[46]. Before the financial crisis between 2000 and 2008, innovation accounted for 51% of productivity growth[47]. Late-stage R&D includes improving processes, making them more efficient, often through automation. Process innovation can improve productivity, reduce costs and help the UK solve the productivity puzzle. However, innovation is not limited to processes only, and product innovation opens up new markets and jobs. The combination of process and product innovation has been found to produce an overall positive effect on employment[48,49,50]. There are opportunities for employment growth through innovation.

STRATEGIC WORKFORCE PLANNING

The UK has a long-standing skills shortage in STEM and most of the engineers and technicians who will be practising in 2030 have already left education[51,52]. Industry 4.0, net zero and emerging technologies all bring new skills demands to deliver innovative solutions into commercial use. A strategic workforce planning function is needed to ensure the supply of key skills to support the whole economy, prioritising and incentivising education, training and upskilling in engineering, sustainability and digital skills[53,54,55,56,57,58].

People

CASE STUDY

VENTILATOR CHALLENGE UK: ASSEMBLING THE SKILLS TO DELIVER VENTILATORS TO THE NHS IN RECORD TIME

Following a call from the UK government to supply the NHS with ventilators in March 2020, Dick Elsy FREng, Chief Executive of the High Value Manufacturing Catapult, assembled a consortium of 33 significant UK industrial, technology and engineering businesses. The consortium brought together expertise from across the aerospace, automotive, motorsport and medical sectors and the wide range of skills needed to deliver the endeavour, including:

- Smiths and Penlon, the two medical device manufacturers at the heart of the consortium. The VentilatorChallenge UK consortium scaled-up the Penlon ESO2 Emergency Ventilator device, which modified proven clinical equipment, and the Smiths paraPAC PlusTM. Both businesses brought expertise in the ventilator design space and an understanding of the clinicians' and regulators' requirements.
- Airbus in Broughton, Ford in Dagenham, GKN Aerospace in Luton and Cowes, McLaren in Woking, Rolls-Royce in Filton and STI in Hook, Smiths Medical in Luton and Penlon in Abingdon adapted manufacturing facilities and trained staff to produce and assemble the ventilators at speed.
- Siemens Healthineers supported the project with medical engineering and regulatory expertise to gain rapid MHRA regulatory approval.
- Siemens provided digital design skills and technology, including the use of digital twins for rapid problem-solving to deliver the project at speed.
- UK-based Formula 1 teams brought a rapid engineering problem-solving capability and culture to drive the pace of the project.

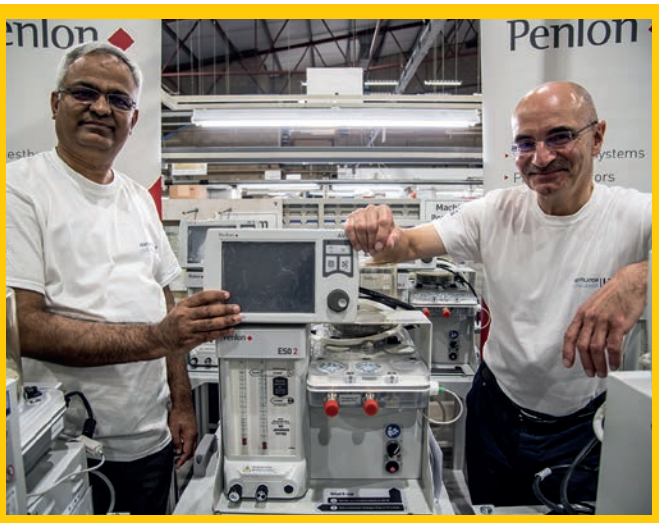


Photo © thisisjude.uk 2020

- Accenture was responsible for accountancy across the collaboration. A cloud network was built and used to track the progress of parts through the supply chain and manufacturing facilities.
- DHL supported project by setting up a complex logistics network that saw them implement an end-to end supply chain in only 1.5 weeks. Despite global competition for parts and lockdown challenges during the pandemic, the supply chains of the different organisations also became key to delivering parts across the consortium. The consortium sourced parts from more than 22 countries, with the furthest distance travelled by a single part being 5,226 miles.
- Microsoft Hololens mixed reality headsets were used to capture the highly specialised ventilator production process to train and upskill the consortium's new 3,000+ workforce in multiple manufacturing sites across the UK and to aid in adhering to social distancing guidelines.

The Ventilator Challenge UK consortium delivered 13,437 ventilators to the NHS by July 2020, reaching a peak production of 400 ventilators a day.

"National Grid estimates that 260,000 new roles will be created in the energy sector by 2050 to deliver net-zero energy[59]"

Partnerships

The relationships, networks and collaborations that enable access to skills, infrastructure, investment and customers, reducing the burden placed on a single company through sharing resources and expertise with others

Which resource gaps could be addressed through a partnership? How can successful partnerships form?

Schemes and funding incentives to drive partnerships and collaboration

Networking support to identify and incentivise partnership building, including through R&D infrastructures

Knowledge exchange across industry and academia

Partnerships take many different forms with partners drawn from businesses of different sizes, universities, regulators, R&D infrastructures and government. Partnerships are a means to manage and share risk by bringing together resources where a single organisation would not be able to go ahead alone[60,61,62].

Partnerships are often the way businesses interact and access people, infrastructure and investment. Partnerships can enable and facilitate R&D in a range of different ways, for example:

- **Shared R&D infrastructures** reduce the financial burden of conducting R&D and provide access to specialist expertise with technicians, such as the services provided by the Catapult Centres.
- **Access to specialised skills** provided by working with one or more organisations, with expertise across the supply or production chain.
- **Sharing investment** reduces the financial burden on each individual organisation.
- **Working with customers** provides a mechanism to customise, test new products and their market potential, while increasing the likelihood customers will invest and take up the product, process or service. For example, Qinetiq ran live exercises with the British Army to gather feedback and test solutions in real time in the field.
- **Engagement with regulators** can improve understanding of regulatory frameworks and reduce the time to regulatory approval, for example ITM Power worked closely with regulators to develop a code of practice for deploying new hydrogen fuelling stations.
  ▶ITM Power
- **Collaboration across supply chains** supports the development of the sector and increases confidence in successfully delivering a new product to market, as with project ESCAPE developing an end-to-end supply chain for automotive power electronics.
  ▶Project ESCAPE
- **Pre-competitive collaborations** support capability building across and within sectors by working together towards solving the greater challenges.

Partnerships

Where can the UK government play a role?

Partnerships can provide game-changing opportunities for businesses that lead to long-term growth in R&D investment in the UK.

Government has a key role in building partnerships, particularly through public R&D infrastructures; their key role in building networks should be valued and incentivised by their KPIs. Government-initiated but industry-led activities and organisations, like the APC and ATI, support strategic R&D partnerships, reaching out across supply chains to innovate and respond to challenges.

Government itself has a key role as a partner. When relevant government decision-makers have a deep understanding of the innovation system and businesses' experiences of interacting with it, better policy and programme design follows.

Government and industry should co-design new industry-led programmes to accelerate R&D in internationally competitive sectors and technologies that are vital to the delivery of national priorities such as net zero and infrastructure. These should draw on the successes of the Aerospace Technology Initiative (ATI) and Advanced Propulsion Centre (APC), which take a strategic approach to support based on a clear analysis of the UK's sectors' needs.

CASE STUDY

DARKTRACE: CUSTOMERS WITH AN APPETITE FOR INNOVATION TO DEMONSTRATE NEW AI PRODUCTS

Photo © Jonathan Browning

Darktrace has developed pioneering, autonomous machine learning software designed to detect and defend against cybersecurity threats. One recent product, Antigena Email, was developed over 18 months by a team of 20: prototyping the algorithms and then engineering a robust, secure and scalable product packaged in a well-designed user interface. Darktrace has a cohort of 'early adopter' customers central to the development of its products. These customers are willing to provide a real-world environment for Darktrace to roll out its products, try out the solutions that have been developed and fix emerging problems. The R&D costs at Darktrace amount predominantly to staff salaries and are financed through revenue, R&D tax credits and external investors.

GOVERNMENT: AN INNOVATION PARTNER AND CUSTOMER

Government, local authorities and public organisations are key partners in late-stage R&D for innovative companies. Whether trialling a new AI company in a local area ▶Vivacity Labs, testing autonomous vehicles with the British Army [Qinetiq], grants and loans from central government [investment], access to publicly funded infrastructure or the NHS participating in clinical trials, none of this development would be possible without a partnership between government and businesses.

Government is also a potential customer of innovation, from improved public services to innovative energy infrastructure or rapid manufacturing of medical devices in an emergency ▶Ventilator Challenge UK. **The UK public sector spent £292 billion on procurement in 2019**[63]. Now is the time to take down the barriers to government procuring innovation and providing the pull to deliver the innovation most needed to solve everyday challenges.

Partnerships

CASE STUDY

PROJECT ESCAPE: BUILDING A UK SUPPLY CHAIN FOR ELECTRIC CAR COMPONENTS TO COMPETE IN A GROWING MARKET

Photo used with permission from McLaren Applied Technologies

McLaren Applied are leading project ESCAPE to develop an end-to-end supply chain for automotive power electronics. The automotive sector is moving to electric cars, introducing new materials into its systems for improved performance. Silicon carbide is one such material, offering significant benefits compared to existing silicon components.

There is an opportunity to develop a UK supply chain in a globally growing market, and provide UK companies with easier access to material to their requirements. Project ESCAPE brings together organisations from semiconductor manufacturing, electronic production and packaging and McLaren as the end user to build a UK supply chain able to supply to McLaren's needs and compete globally.

McLaren has two future products based on this project, providing certainty to future resourcing. The project brings together £25 million investment, including £9.8 million in grants from the Advanced Propulsion Centre.

CASE STUDY

QINETIQ: TESTING AN AUTONOMOUS LAND VEHICLE IN LIVE EXERCISES WITH THE BRITISH ARMY

Photo © Ministry of Defence

QinetiQ is developing an autonomous uncrewed ground vehicle (UGV). Through a Defence and Security Accelerator programme launched in 2017, it was able to take its prototype into a live experiment with the British Army. The development team was on-hand to implement changes based on feedback coming in during the live exercises. This iterative feedback loop was described as invaluable to product development and an important part of co-creation between the users and engineers. The UGV is designed to deliver supplies across challenging terrain, working in concert with an uncrewed air system (UAS) and the controlling software, with applications in several different situations, including civil applications such as disaster relief. The Defence Science and Technology Laboratory awarded a contract to QinetiQ for its first fleet of autonomous UGVs in March 2020.

CUSTOMERS AND LATE-STAGE R&D

Bringing customers into the R&D process in the late stages can help build market demand and strengthen the business case for innovative products, as well as ensuring the product delivers to the specific needs of its future users. Customers can contribute to the financing of the project, through contracts for orders or customisation. There can be disadvantages to seeking investment from future customers, as they may introduce preferential clauses limiting sales to competitors for a defined period of time, for example.

Partnerships

CASE STUDY

UNIPART MANUFACTURING INVEST IN LATE-STAGE R&D THROUGH JOINT VENTURE WITH COVENTRY UNIVERSITY TO ACCELERATE GROWTH

Photo used with permission from Unipart Manufacturing

Unipart Manufacturing recognises the importance of investing in new skills and capabilities at the same time as investing in existing business as crucial for future growth and success. Doubling up on investment, in times of financial crisis, is an almost impossible task.

Drawing on technology roadmaps, company strengths and industry knowledge, Unipart Manufacturing approached Coventry University with a clear vision for collaboration with industry and academia, opening up funding avenues and attracting customer interest in the latest technological innovations to strengthen its approach to late-stage R&D.

Out of this collaborative relationship, a pioneering joint venture was born: the Institute for Advanced Manufacturing and Engineering (AME).

Co-located on one of Unipart Manufacturing's sites, AME creates a talent pipeline of graduate engineers, provides a facility for developing new manufacturing processes and products to support the customer base. It is where new customers start their journey with Unipart Manufacturing. To make the collaboration financially viable, research projects with a customer pull or contract are prioritised and where grant funding can be secured. This funding boost leads to jobs created and further benefits the UK economy by demonstrating the UK as serious leaders in R&D technologies. The approach has driven a culture of collaboration with not just Coventry University, but with suppliers, customers, technology partners and funding bodies.

AME provides a unique blend of business and academia ensuring Unipart Manufacturing's late-stage R&D is financially viable and has resulted in £250 million in new business, including the launch of Hyperbat, a significant new entrant into the manufacture and assembly of high-voltage battery systems.

PRE-COMPETITIVE COLLABORATION: BUILDING CAPABILITY IN AND ACROSS SECTORS

Pre-competitive R&D does not produce a competitive advantage for one company, rather it builds the capability across the sector. The Industrial Strategy Challenge Fund (ISCF), and industry-led joint ventures with government such as the Advanced Propulsion Centre (APC) and the Aerospace Technology Institute (ATI) provide funding and collaboration building services that bring together companies to solve a shared problem. For example, electric flight is a shared pre-competitive challenge for the aerospace sector. The APC and ATI support and effectively match-make across the automotive and aerospace sectors, respectively, to conduct R&D for the transition to low-carbon and electric transport. Such a transition would be costly and challenging for a company to do alone, whereas this approach carries the sector together towards a common goal.

Market environment

The policies and frameworks influencing and producing opportunity or challenge for companies conducting late-stage R&D and commercialising innovation, including regulation, trade policy, intellectual property, and government strategies

R&D investment decisions are highly complex and sensitive to the individual nature of the company. The market environment is key in that it influences the time it takes to develop a new product as well as the appetite of investors and customers to buy the new product, process or service.

The market environment also impacts the wider environment experienced by businesses. Businesses must consider a broad range of factors including performance of the firm and profit margins, tax environment, market trends, intellectual property rights, trade and export policies, and opportunities posed by government strategies and roadmaps.

Systems approach by a joined-up government

Policy levers that influence businesses ability to undertake successful R&D and innovation are spread across the whole of the government, from immigration policy in the Home Office, to export policies in Department for International Trade, from R&D tax reliefs in HM Treasury and HMRC, to 'innovation policy' in BEIS. The policy levers that impact businesses' wider ability to trade and grow are similarly spread. Therefore, a whole government systems approach should be taken to the UK's R&D and innovation ambitions. This will ensure that the different elements of the strategy work together as a coherent whole and will enable risks to be mitigated more effectively.

From concept to market, engineering businesses engage with a broad range of government departments and agencies. Each of these interactions has the potential to facilitate or inhibit businesses in delivering their strategy, with knock-on effects for innovation and R&D investment. Engineering companies find strategic engagement across UK government organisations frustrating, fragmented, and not joined-up[64]. The problem exists across government organisations, although the challenge presents differently across businesses and sectors. This makes the UK less attractive for businesses to invest in R&D.

Market environment

Attracting R&D investment in a globally competitive market

Businesses compete in global markets, and they also choose the location of their R&D activities in a global market. The UK offer for attracting businesses to locate their R&D activities here must be competitive across the board, enable businesses to conduct R&D and facilitate the management of the corresponding risk to the business.

The UK is outlining a bold, global vision for the UK as an outward-looking leading trading nation and a first-choice destination for inward investment and international talent. The UK's offer of support for late-stage R&D must be sold as part of that vision, both nationally and globally.

Where can the UK government play a role?

The ecosystem in which businesses conduct R&D is broad and complex. Government sets the tone and direction with strategies and policies that provide certainty to business and create greater opportunity for commercialisation.

To create a supportive environment for engineering business R&D and innovation, all government organisations must share a clearly defined vision of success and be well coordinated. This will provide a long-term stable backdrop for business decisions and investment.

BEIS and UKRI should clearly signpost the UK's offer for late-stage R&D and innovation through an accessible online interface to facilitate navigation for the business user, and work with Department for International Trade (DIT) to market it globally as part of a joined-up UK innovation pitch to international investors.

COVID-19: STIMULATING BUSINESS R&D INVESTMENT DURING AN ECONOMIC CRISIS

The pandemic has rapidly altered the business environment in which innovative startups and engineering R&D-intensive businesses operate. Reducing or outright halting R&D activities is one of the first cost-saving measured that businesses take during falling demand and cash flow difficulties. The Bank of England DMP survey found that R&D spend was expected to reduce by 9.4% to 16.7% in 2020 in light of the COVID-19 crisis[67]. However, R&D is also recognised by businesses as part of the solution for economic recovery[68].

For some industries, recovery will not mean returning to pre-pandemic business as usual. Instead they will require innovation to survive and adapt to the 'new normal' with different ways of working and dramatically changed supply and consumer demand.

To build back better and sustainably, we will have to help businesses continue R&D and ensure that businesses who have halted R&D activities in the initial crisis response have capacity and capability to progress R&D activities in the UK and reposition themselves in a reformed global market.

"Only 47% of people believe that innovation has had a positive impact on people like themselves[65]"

Market environment

CASE STUDY

BAE SYSTEMS: COMMERCIALISING A DISRUPTIVE INNOVATIVE PRODUCT WITH OPPORTUNITIES ACROSS DIFFERENT MARKETS

BAE Systems operates in a highly competitive sector: defence. As such they drive forward R&D, for example an optical technology that enables a viewer to see an image projected into their eyes whilst still being able to see the actual backdrop meaning a pilot can see critical information while flying, a driver can be shown data while driving or a soldier can see vital stats on the battlefield.

In 2005, BAE Systems licenced on an early-stage technology from a University of Cambridge University spin-out before developing its own technology in this field. It then took 10 years to develop the technology to a prototype stage where it could be shown to customers to bring them on board. The first commercial product, for the defence market, was a head-up display, 50% lighter, brighter and more capable of handling information than existing technology. It was then developed further into augmented reality glasses to be used across a range of military and commercial markets and generate new demand back into the defence sector. As a result of BAE Systems continuous incremental investment of over £15 million over 15 years there is now significant potential for the technology in multiple markets. However, the late-stage investment to adapt and tailor the core technology to each new market can be significant. This naturally restricts BAE Systems' ability to maximise the full market potential when balancing overlapping investment requirements against shareholder expectations of business returns in the near term.

Photos used with permission from BAE Systems

MARKET PULL VS TECHNOLOGY PUSH[66]

Market pull is generated when the market has identified a problem and engineers develop a solution to that problem. Here, the risk of conducting late-stage R&D is reduced for businesses with a ready-waiting customer. This contrasts with technology push, where engineers have identified a new product that the market is not (yet) asking for. In the latter case, market interest in the new product needs to be generated during late-stage development to ensure commercial success, and although it can be challenging there are many examples of success. Partnerships with customers is one way that businesses approach generating market pull.

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Companies interviewed

Interviews were conducted with chief technology officers, chief engineers, heads of R&D, or in some cases, chief executives from 32 companies, including:

- BAE Systems
- BP
- BT
- CCm Technologies
- Darktrace
- Domino Printing Services
- Electricity North West
- GKN Automotive
- GSK
- Ineos
- ITM Power
- M Squared Lasers
- McLaren
- Procter and Gamble
- QinetiQ
- Radio Design
- Renishaw
- Ricardo
- Rolls Royce
- Siemens UK
- Spirit AeroSystems Belfast
- Surrey Satellite Technology Ltd
- Unipart Manufacturing
- Vivacity Labs
- WSP

We also spoke to the following organisations:

- Aerospace Technology Institute
- High Value Manufacturing Catapult
- Highways England
- Nuclear Innovation and Research Office

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