UNIVERSITY OF CAMBRIDGE

Cambridge Industrial Innovation Policy

UK performance in technology scale-up

Translating and anchoring new science and engineering into commercially viable products and businesses

Cambridge Industrial Innovation Policy
Institute for Manufacturing, University of Cambridge

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This study was commissioned by the Department for Science, Innovation and Technology (DSIT) to inform the work of the National Technology Adviser, Dr Dave Smith.

Contributors

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UK performance in technology scale-up

KEY FINDINGS

The UK's seemingly positive performance in technology scale-up and aggregated innovation metrics masks the fact that the country's rankings are underpinned by activities related to a small number of dominant sectors, with life sciences, fintech, and software dominating

- For example:
  - Pharmaceuticals and biotechnology are the most used patent technology fields for UK universities and spinouts.
  - The top technology focus of all UK-origin patents are computer technology (software), pharmaceuticals, and medical technology.
  - Pharmaceuticals constitute the largest number of UK spinouts, whereas AI is the largest sector outside traditional classifications.
  - UK venture capital investments were dominated by fintech, health, and enterprise software in 2023.
  - The most successful UK high-value startups are not spinouts, tending to focus on service-oriented sectors such as fintech, enterprise software, and insurance rather than hardware.
  - Pharmaceuticals and software development represent 33% of R&D performed in the UK by domestic and foreign-owned businesses of all sizes.
  - Pharmaceuticals accounts for 49% of UK-owned business global R&D, while UK-owned firms are largely absent in software, tech hardware, and electronic and electrical hardware, which represent 42% of global business R&D.
  - Software was the top industry by R&D tax credits received in 2022–23.

Consulted leaders from technology spinouts/startups consistently paint a picture of a UK that excels in early-stage innovation and R&D but faces significant systemic challenges in the transition to large-scale commercialisation and manufacturing in sectors outside the dominant ones

  - The interviewees highlighted that while the UK boasts an excellent science and innovation base, translating this into large-scale domestic manufacturing and commercialisation is hampered by issues accessing appropriate finance, the cost and complexity of manufacturing, securing skilled labour, and navigating an unpredictable and often unsupportive policy environment.
  - The consulted experts also mentioned that foreign markets, particularly the USA and Germany, are often seen as offering more attractive conditions and incentives for manufacturing and commercialisation to ensure firm profitability.
  - While some government initiatives like R&D tax credits and early-stage grants are seen as valuable by the consulted stakeholders, others, like catapults, are seen as opportunities for further development.
  - The interviewees suggested that the UK needs to address these fundamental challenges to become a more attractive location for technology companies looking to scale up and manufacture domestically; otherwise, the economic benefits of its strong innovation base risk being realised elsewhere.

KEY FINDINGS

Mutually reinforcing industrial innovation systems in key domains/sectors

- It is beyond the scope of this study to fully disentangle the causal dynamics behind the strength of dominant sectors: Is the strength of UK life sciences commercialisation, venture capital (VC), and scale-up activity primarily a consequence of the strength of the academic research base? Or is it a consequence of the investment, directionality, and resource spillovers from the industrial base?
- Based on the evidence considered here, there are strong plausibility arguments that both parts of the industrial innovation system contribute to the success of, for example, the UK life sciences "scale-up" activities, in a mutually reinforcing virtuous cycle.

Role of "primes" – directionality, resource spillover, and value capture

- Given the success of "scale-up" ecosystems involving established industrial value chains (potentially anchored by large primes), UK national technology strategies could carefully consider the viability of innovation pathways to scale-up (and industrial value capture) in the absence of large R&D-intensive firms and their supply chains. In principle, "primes" can make a range of contributions to a thriving industrial innovation system, including:
    - offering directionality to SMEs by highlighting promising technology/market opportunities, including facilitating the involvement of supply chain firms in wider UKRI R&D programmes and networks built around these opportunities
    - developing human resources, some of which can eventually be hired by scale-up firms, accelerating innovation capabilities, absorptive capacity for emerging technologies, and their deployment at scale
    - being an anchor tenant for an "industrial commons" of specialist engineering, contract manufacturing, and R&D services firms, which can supply "scale-up"-enabling support services to the wider scale-up ecosystem, and
    - supporting the viability of capital-intensive technological (scale-up) infrastructure within the ecosystem (pilot lines, testbeds, etc.).

Pathways to "scale-up" within the UK economy

- Whether through investing and/or acquiring UK spinouts and startups, the migration of UK "unicorns" or foreign ownership of industrial R&D operations in the UK, the mobility of UK-developed innovations at key phases of the technology scale-up process is striking.
- Again, aggregate metrics related to "upstream" innovation activities mask the vulnerability of innovation to relocation outside the UK, at key industrial scale-up transition phases (where new capabilities and resources are required).

Introduction

UK performance in technology scale-up

Introduction (1 of 2)

Scaling up emerging technologies (such as advanced materials, biotechnology, and quantum) into the industries and products of the future is a common priority in leading economies. This global race is driven by economic policy, geopolitics, and national security concerns.

Scaling up disruptive science-based technologies may require new R&D-based solutions to tackle manufacturability challenges; and novel tools, production technologies, and facilities may be needed to develop, test, and demonstrate emerging applications. To translate scientific leadership into industrial performance, countries need policies that support not only scientific discovery and early-stage commercialisation but also the critical later stages of the innovation process.

In particular, policies may be needed to help make the UK the location of choice for next-generation factories – creating thousands of new and better jobs – and to support supply chains and regional clusters to upgrade their technical capabilities, enabling them to compete globally for high-value industrial opportunities.

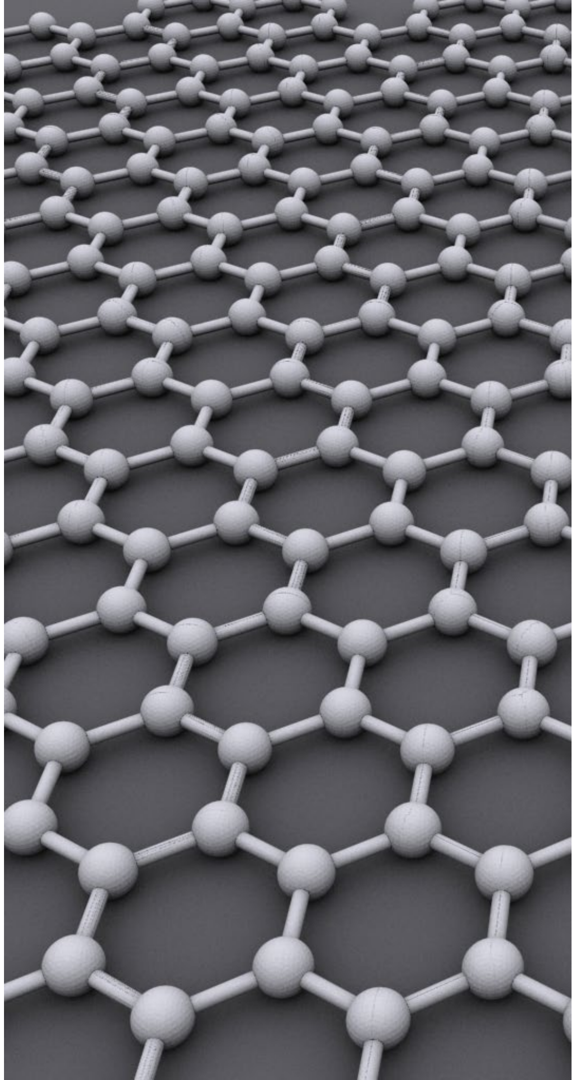
However, there are significant variations in how the term “scale-up” is understood. There are policy implications for a range of different innovation activities related to the term, including the engineering scale-up of a novel technology, the production scale-up of a technology-based product, the operational and organisational scale-up of a technology-based business, or even the scaling up of product value chains or markets. A key challenge for programmes addressing scale-up is to integrate support, and facilitate linkages and alignment, between different innovation activities.

Introduction (2 of 2)

In this report, technology scale-up is defined as processes that help new science and engineering knowledge to make its way into products and companies for the first time by overcoming challenges to technical and organisational performance at scale. In this approach, scale-up is framed as part of the larger processes of technological commercialisation and industrialisation, focusing on overcoming “manufacturability” challenges.

The aim of the report is to explore how effectively the UK translates new science and engineering research into commercially viable products and businesses. In particular, it addresses the following objectives:

- It provides an overview of existing definitions of scale-up and suggests a framework to explain its multiple dimensions.
- It examines how effective the UK innovation system is at converting innovation inputs into innovation outputs that can translate into economic value.
- It explores the role and effectiveness of spinouts, startups, and established firms in driving the technology scale-up process, as well as the UK’s ability to retain value from these processes.



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SECTION 1

Understanding technology scale-up: definitions, dimensions, and actors involved

What common definitions of scale-up are found in the literature?

What are the key dimensions involved in technology scale-up?

Who are the main actors involved in the technology scale-up process, and how are they related?

Section 1 – Key findings (1/2)

KEY FINDINGS

"Technology scale-up" generally refers to the process by which new science or engineering concepts are translated from the research stage into commercially viable products or services. Rather than simply describing a rapidly growing business (often called a "scale-up" in broader entrepreneurship contexts), technology scale-up centres on the maturation and commercialisation of innovative technologies. It involves a series of steps that take a laboratory concept through prototyping, development, and production and into the market.

There are multiple definitions of "technology scale-up":

- **Commercialisation perspective:** From a business standpoint, technology scale-up focuses on how novel intellectual property or research breakthroughs are integrated into new or existing firms. This includes everything from securing funding to building teams that can navigate regulatory approvals, marketing, and distribution.
- **Technical development perspective:** In R&D circles, technology scale-up is the progression from small-scale research or proof-of-concept prototypes to full-scale, real-world applications. This includes pushing a technology through increasing levels of technical readiness, ensuring it can perform reliably under practical conditions, and setting up the production systems and supply chains needed for mass production and commercialisation.

While the term "technology scale-up" captures a broad process, it can be broken down into several key dimensions:

- **Technology readiness scale-up:** moving a technology from concept (or lab prototype) to a minimum viable product (MVP), and then to a fully tested, reliable commercial product.
- **Manufacturing/production scale-up:** transitioning from producing small batches or one-off prototypes to high-volume manufacturing.
- **Supply-chain scale-up:** ensuring a robust, reliable, and cost-effective supply of materials, components, and services that support production and distribution.
- **Business model and market scale-up:** launching or expanding a viable commercial model and capturing market share for the new technology.

Section 1 – Key findings (2/2)

KEY FINDINGS

Technology scale-up is a multifaceted process that depends on a network of stakeholders, each contributing specialised resources and expertise. Spinouts, startups, and established corporations are the principal actors driving technology scale-up:

- **Universities and research institutes:** conducting foundational research and generating early-stage intellectual property (IP); offering specialised resources such as laboratories, scientific equipment, and expert researchers; and providing technology transfer offices (TTOs) to commercialise research outputs.
- **Spinouts and startups:** transforming patented or prototype-level discoveries into market-ready products; fostering agility and risk-taking, particularly in deep-tech or novel fields; and driving job creation and sectoral diversity in local innovation ecosystems.
- **Established corporations:** integrating new technologies into mature product lines, supply chains, and global distribution networks; and providing expertise in manufacturing, large-scale commercialisation, and regulatory compliance.
- **Venture capital and other private investors:** supplying critical funding at the seed, early, and growth stages; and offering mentorship, strategic direction, and networks to help startups scale.
- **Government and public agencies:** providing grants, tax incentives (e.g. R&D tax credits, patent box schemes), and policy frameworks that encourage innovation; supporting public research infrastructure and collaborative platforms (e.g. catapult centres, research councils); and enforcing regulations while promoting best practices and standards.
- **Research and technology organisations (RTOs):** providing technical advisory; access to capital equipment; and skills development.
- **Supply chain partners:** providing critical materials, manufacturing, and logistics services to enable production scale-up; and often co-developing custom solutions for new technologies.

1.1. Scale-up definition (1/3)

Business perspective

1. Understanding Firm Growth – Helping SMEs Scale Up (OECD, 2021):

- The definition of "scalers" (firms) adopted by the Organisation for Economic Co-operation and Development (OECD) mirrors the Eurostat–OECD definition of "high-growth firms" illustrated in the *Eurostat-OECD Manual on Business Demography Statistics* (2007).
- Scalers are non-micro firms that grow in employment and turnover at a minimum yearly rate of 10% over a period of 3 consecutive years:
  - "Employment scalers" refers to firms that scale up in employment.
  - "Turnover scalers" are firms that scale up in turnover, meaning the total sales of the products and services by the firm within a given year.
  - "High-growth" (employment or turnover) scalers are firms that grow in employment or turnover at a yearly rate of more than 20% over 3 consecutive years.
- For all definitions, there is the additional condition that the firm must have at least ten employees in the year in which the fast growth begins.

1.1. Scale-up definition (2/3)

Technical development perspective

2. Accelerating US Advanced Manufacturing (PCAST, 2014):

- Scale-up can be defined as translating an innovation into a market. New manufacturing technologies face significant technical and market risks during scale-up. The path to successful commercialisation requires technologies to function well at large scale and markets to develop to accept products produced at scale. It is a time when supply chains must be developed, demand created, and capital deployed.

- There are three requirements to achieving commercial scale with promising advanced manufacturing technologies:
    - networked supply chains
    - rapid diffusion of technology through the networked supply chains, and
    - access to capital.

1.1. Scale-up definition (3/3)

Technical development perspective

3. US National Institute of Health (2024). Manufacturing Scale-Up of Drugs and Biologics:

Scale-up process

- The transition from laboratory to commercial scale is a multi-step endeavour that requires meticulous planning and execution.

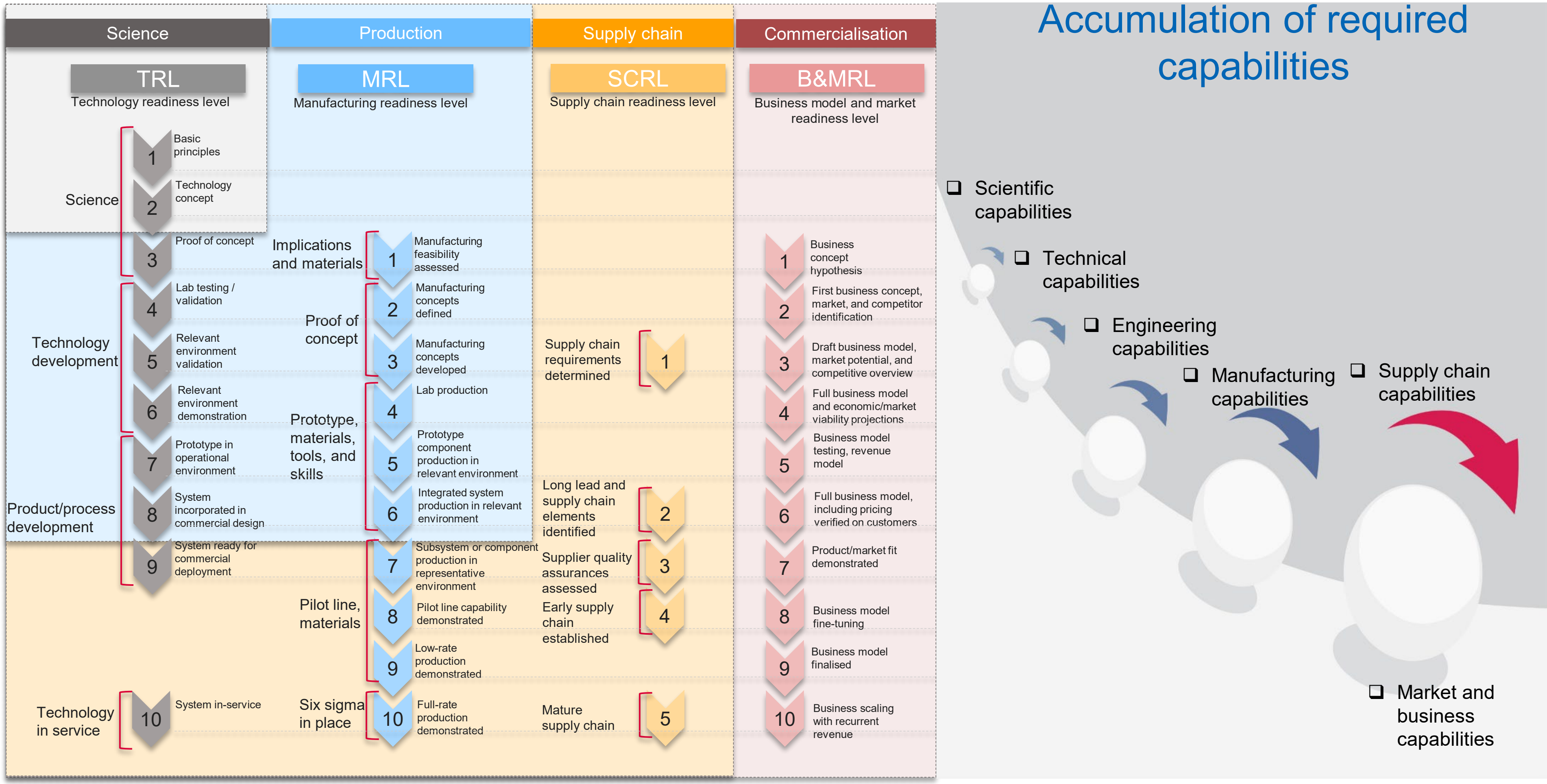
Process development versus scale-up

- **Process development:** This stage focuses on crafting and refining the production process, exploring various methods, adjusting parameters, and monitoring outcomes to establish the most efficient production method.
- **Scale-up:** The scale-up process involves increasing the production volume, often translating a bench-scale process into an industrial-scale operation.

Stages of scale-up

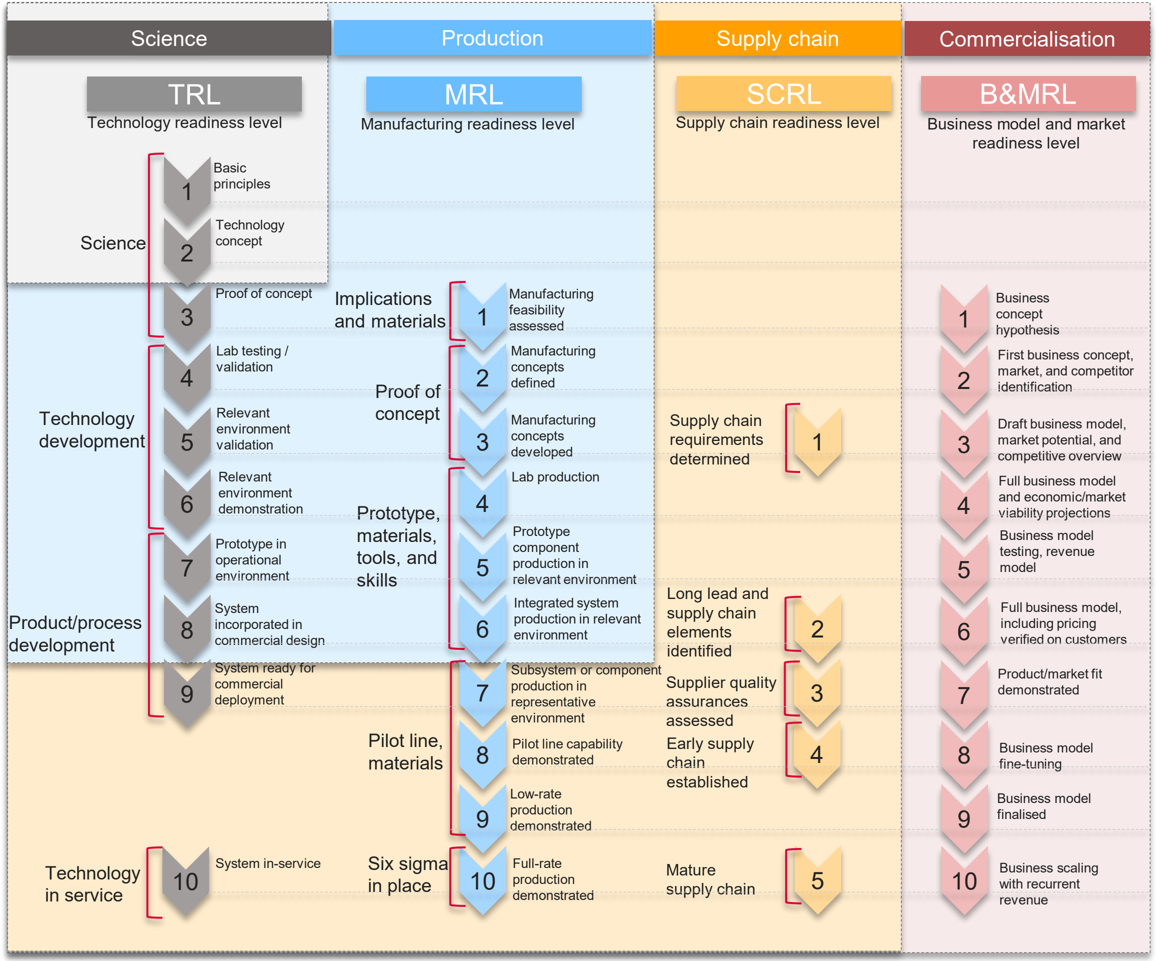
- **Laboratory scale:** Initial development and testing occur on a small scale, allowing for process tweaking without the risks and costs associated with larger scales.
- **Pilot scale:** This intermediary stage is crucial for fine-tuning the production process in a near-real-world environment to anticipate and rectify potential issues. The steps in the process (or unit operations) are defined and ideally locked.
- **Commercial scale:** The definitive stage where production is ramped up to meet commercial demand. Process stability is critical at this juncture, as changes can significantly impact costs and product integrity – unit operations are not changed except to accommodate increased scale.

1.2. The multidimensional nature of "scale-up" (1/5)



Source: Author's creation, based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

1.2. The multidimensional nature of "scale-up" (2/5)

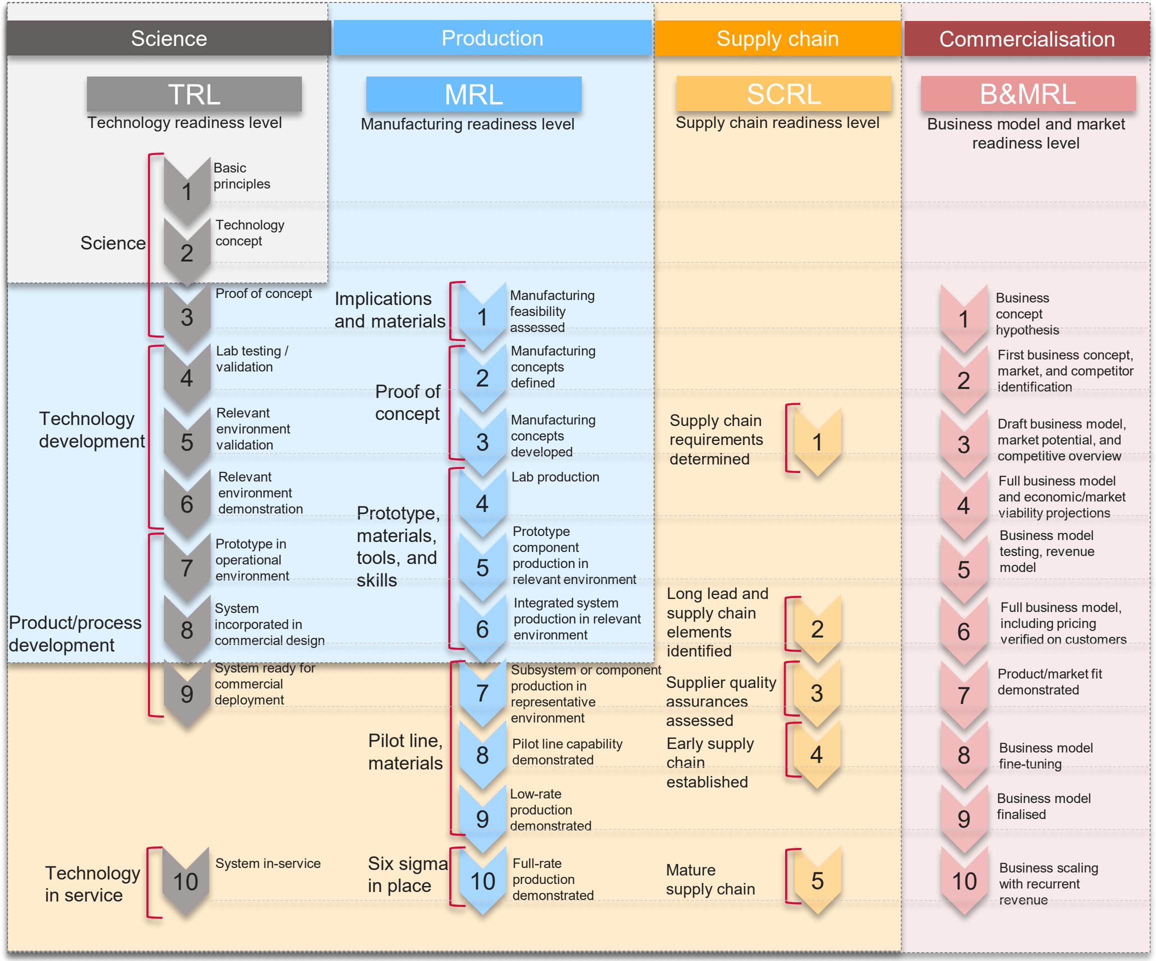


The review of recent international manufacturing R&D policies and programmes suggests the need for a broader conceptualisation of "scale-up" and increased efforts to align and synchronise policy efforts addressing distinct aspects of scale-up. In particular, the review suggests there is merit in distinguishing between the following dimensions of scale-up:

- **Technology development scale-up**. For many of the most promising emerging technologies highlighted in international manufacturing research strategies (e.g. synthetic biology, quantum technologies, and graphene), there is significant technical uncertainty and risk involved in developing novel products in the process of transforming a laboratory prototype into an integrated and packaged product demonstrator with the potential for full-scale production. In particular, a series of technology readiness levels (TRLs) need to be achieved. This development process can be especially challenging for devices based on integrated converging technologies, as production processes that are appropriate for one technology may impact the functionality of another.

Source: Author's creation, based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

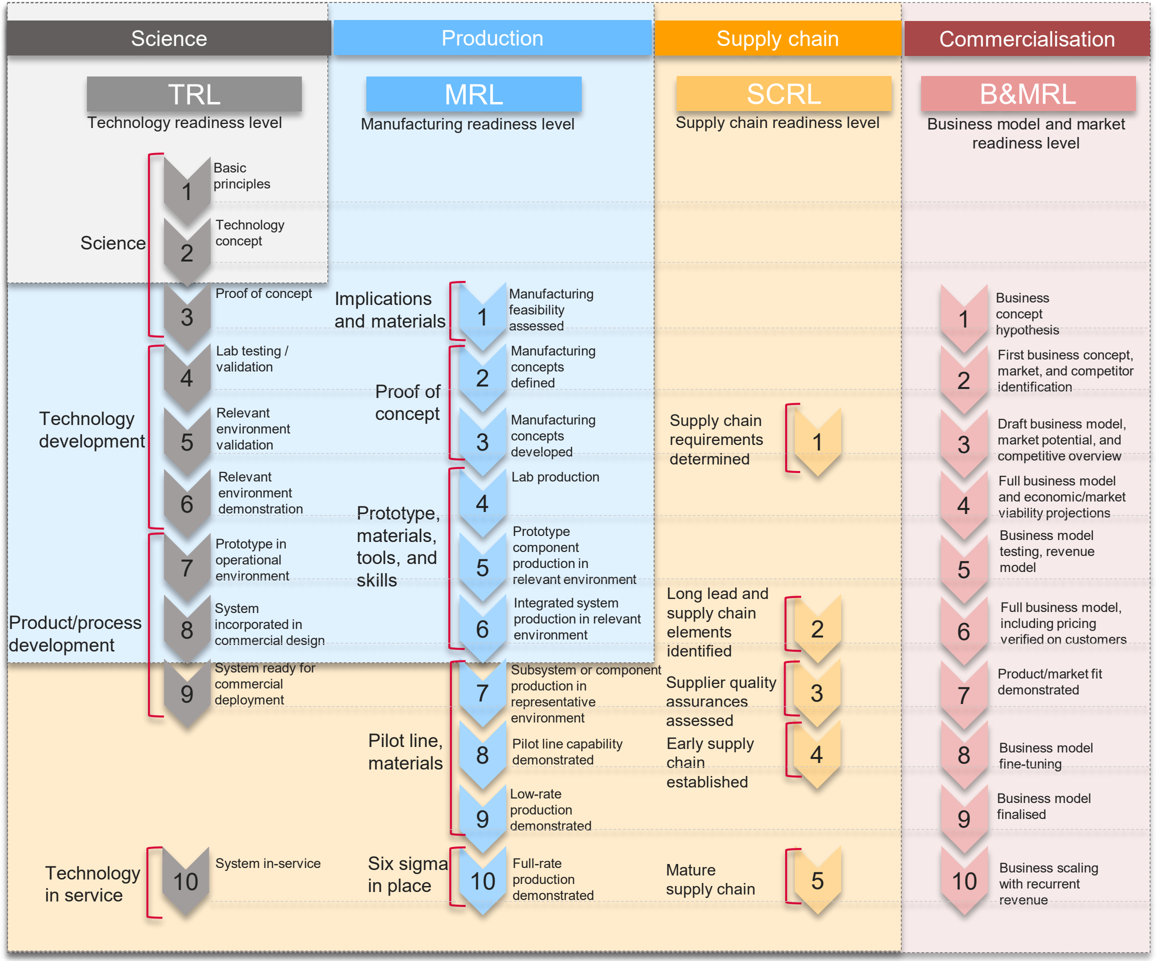
1.2. The multidimensional nature of "scale-up" (3/5)



- **Manufacturing process/production scale-up.** Scale-up R&D is not just about product technology innovation. Significant R&D effort is also required for novel production/process technologies (e.g. additive manufacturing and laser-based processing) or for adapting processes and techniques for the manufacture of novel key enabling technologies. In particular, a series of manufacturing readiness levels (MRLs) must be achieved. Many novel production technologies and processes require demonstration of their functionality, applicability, and cost-effectiveness at greater production volumes, higher throughput rates, and realistic process-line factory environments. In this context, there is a potentially significant role to be played by pilot line programmes, demonstration and testing infrastructure, and intermediate R&D institutes.

Source: Author's creation, based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

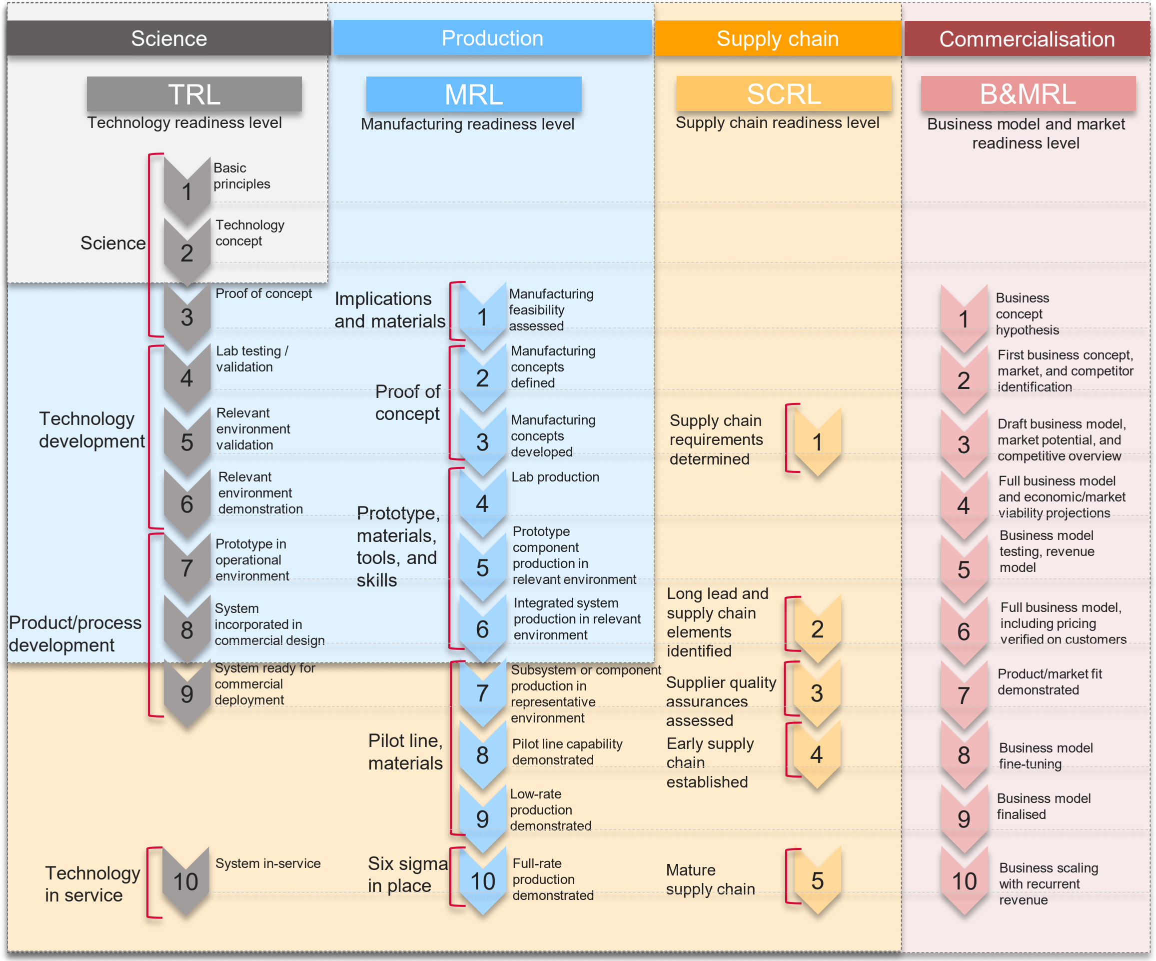
1.2. The multidimensional nature of "scale-up" (4/5)



- **Supply chain scale-up**. The effective industrialisation of an emerging technology also requires the development of new value chains – developing and redistributing manufacturing-related capabilities to support new products, business models, and markets. In the next production revolution, manufacturing scale-up innovation may require cooperation across the entire industrial value chain, with suppliers of input materials (and components/subsystems) and equipment/tool vendors needing to synchronise their innovation efforts, engaging closely with end users. In this context, there is a significant role to be played by linkage programmes, institutions, and diffusion mechanisms (e.g. intermediate R&D institutes, technology diffusion organisations, and technology roadmaps).

Source: Author's creation, based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

1.2. The multidimensional nature of "scale-up" (5/5)



- **Business model and market scale-up**. The scale-up viability of an innovation from a commercial perspective represents a key dimension, as it is necessary to ensure that the idea can be transformed into tangible and sustainable business benefits. This involves assessing the business model, market strategy, financial projections, and overall market potential. This dimension works by guiding innovators through levels that start with a basic understanding of the market and business environment, progressing to more detailed plans for revenue generation, scaling, and sustainability. By systematically addressing these aspects, innovators can identify potential market challenges, refine their business strategies, and increase the likelihood of successful commercialisation and long-term growth.

Source: Author's creation, based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

1.3. Actors involved in driving technology scale-up (1/2)

Technology scale-up is a multifaceted process that depends on a network of stakeholders, each contributing specialised resources and expertise. Spinouts, startups, and established corporations are the principal actors driving technology scale-up.

- **Universities and research institutes:** conducting foundational research and generating early-stage intellectual property (IP); offering specialised resources such as laboratories, scientific equipment, and expert researchers; and providing technology transfer offices (TTOs) to commercialise research outputs.
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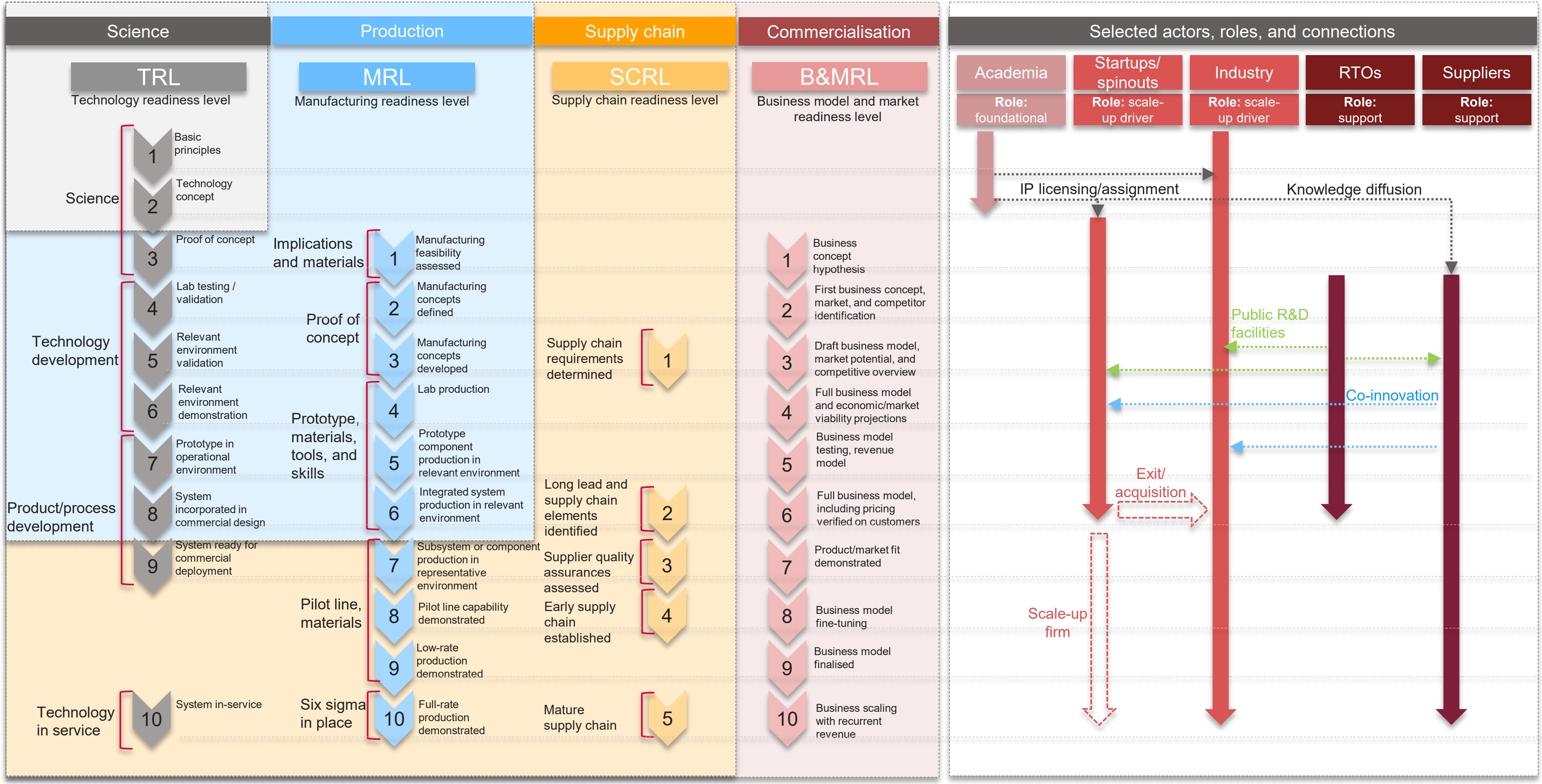
1.3. Actors involved in driving technology scale-up (2/2)



Source: Author's creation, based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

SECTION 2

UK innovation system's performance and ability to convert innovation inputs into innovation outputs

Is the UK national innovation system over- or underperforming in relation to comparator nations?

How does the UK perform in innovation inputs?

How does the UK perform in innovation outputs?

Section 2 – Key findings (1/2)

KEY FINDINGS

Overall, the UK innovation system stands out as a strong innovator, consistently performing well in global innovation indices, especially in terms of innovation outputs like scientific excellence, VC funding, IP receipts, and unicorn valuations. It ranked fifth among 133 economies in the Global Innovation Index (GII) 2024. However, the country's innovation inputs remain behind its outputs, indicated by relatively modest rankings in education spending, STEM graduates, and certain measures of private-sector R&D intensity. Moreover, while the UK demonstrates above-average performance in basic and applied research, it invests a lower proportion in experimental development than leading OECD nations. This may explain its lag in scaling market-facing technologies (measured by revenue generated from improved products, whether new to the enterprise or new to the market) and IP applications compared to its peers. However, aggregate innovation metrics mask the fact that the UK's rankings are underpinned by activities related to a small number of sectors, with life sciences dominating.

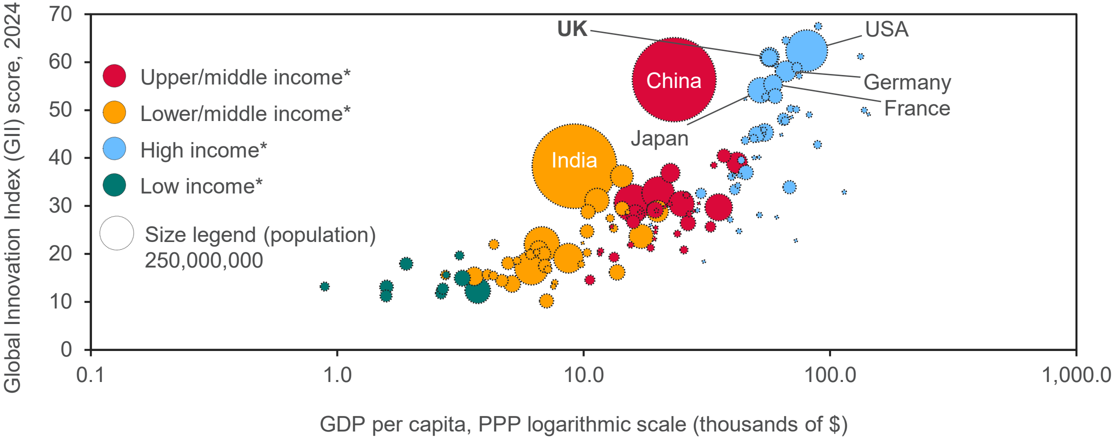
- **Strong overall ranking in the Global Innovation Index (GII):** The UK is consistently recognised as a leader in global innovation (fifth among 133 economies and third in Europe in WIPO's Global Innovation Index (GII) 2024). This reflects a strong performance across a balanced set of roughly eighty innovation indicators.
- **Better at outputs than inputs:** The UK ranked third on innovation outputs and tenth on innovation inputs within the GII 2024. Some outputs (e.g. citable documents, H-index, IP receipts, unicorn valuations) are very strong. While some inputs (e.g. education spending, R&D intensity) are solid, the system generally lags behind the top performers.
- **High performance in unicorn valuations and venture capital:** The UK's unicorn valuation tops the global list (rank 1 at 4.92% of GDP). Venture capital inflows remain comparatively strong (indicator rank 9), although they declined in value by 34.9% in 2023.
- **Room to improve in education and STEM graduates:** Expenditure on education stands at 5.4% of GDP (indicator rank 32), while graduates in science and engineering represent 22.26% of total graduates, ranking 64th, suggesting a potential bottleneck for the talent pipeline.
- **Mixed R&D indicators:** Overall R&D intensity is 2.9% of GDP (indicator rank 11). The UK leads G7 countries in the share of R&D performed by higher education, but the number of researchers (4763.48 FTE/million) ranks 24th globally, suggesting potential for more private sector absorption of skilled researchers. Government R&D emphasises basic research (39%) more than many of its OECD peers, but it invests less in experimental development (19% versus an OECD benchmark of ~26%).

Section 2 – Key findings (2/2)

KEY FINDINGS

- **Patent and high-tech manufacturing gaps:** Patents by origin (16,880 in 2022) place the UK at rank 16, down 1.97% from the previous year, while high-tech manufacturing makes up 40% of total manufacturing (rank 26), signalling modest competitiveness in advanced manufacturing.
- **Underperformance in intellectual property (IP) applications:** Despite strong IP receipts (rank 8), the UK lags behind the EU average on design applications (34% of EU average) and has lower patent application intensity than major global innovators like China. PCT patents by origin (5,590 in 2023) rank the UK 20th, down 2.27% from the previous year.
- **Divergent performance in the EU context:** The UK is classified as a “strong innovator”, at 114.8% of the EU innovation performance average. Notably, while the UK excels at government support for business R&D (187.8% of EU average), its overall performance growth lags behind the EU average (where innovation performance grew by ~10% between 2017 and 2024). Internet infrastructure, IP applications, and market-facing technology scale-up remain areas where the UK underperforms against EU benchmarks.
- **Strength in scientific publications but constraints in private R&D:** The UK produces the most publications per 1,000 people among G7 countries and China. But it files only 10% of China’s patent applications per US$100 billion GDP despite a comparable R&D-to-GDP ratio. Private sector engagement in late-stage R&D, particularly experimental development, remains below that of leading OECD nations.
- **Structural emphasis on basic and applied research, underinvestment in experimental research:** Within business enterprise R&D (BERD), the UK allocates 14% to basic research, higher than the OECD average (8%), while it spends 35% on applied research, exceeding the OECD average (30%). The UK also commits 51% to experimental development, below the top OECD benchmark of 62%. Within government R&D (GOVERD), the UK spends 39% on basic research (versus 24% OECD average) and allocates only 19% to experimental development (compared to 26% across leading OECD nations).

2.1. The UK ranks as a leader in innovation capabilities based on composite measures across a range of inputs and outputs, driven by the excellence of key sectors, particularly in life sciences



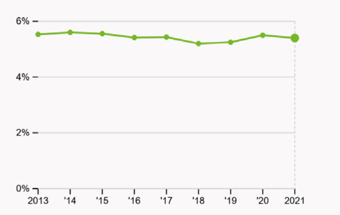
UK GII Ranking (2020–24)			
Year	**GII position**	**Innovation inputs**	**Innovation outputs**
2020	4th	6th	3rd
2021	4th	7th	6th
2022	4th	7th	3rd
2023	4th	6th	2nd
2024	**5th**	**10th**	**3rd**

- The Global Innovation Index (GII) ranks world economies according to their innovation capabilities. Consisting of roughly eighty indicators, grouped into innovation inputs and outputs, the GII aims to capture the multidimensional facets of innovation.
- Overall, the UK ranked fifth among the 133 economies featured in the Global Innovation Index (GII) 2024.
- The UK ranked fifth among the 51 high-income group economies in 2024 and third among the 39 economies in Europe in 2024.
- The UK performed better in innovation outputs (third) than innovation inputs (tenth) in 2024.
- However, aggregate innovation metrics mask the fact that the UK's rankings are underpinned by activities related to a small number of sectors, with life sciences dominating.

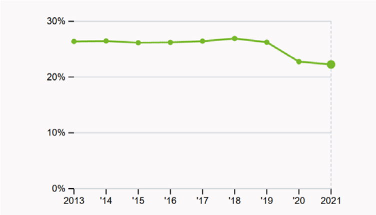
***Note:** World Bank Income Group Classification: high income, upper/middle income, lower/middle income, low income.
Source: WIPO (2025). Global Innovation Index 2024.

2.2. The UK ranked 10th in innovation inputs out of 133 economies in the Global Innovation Index (GII) 2024

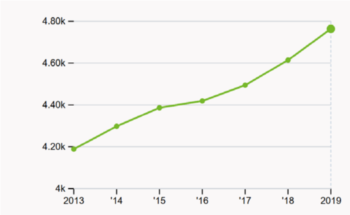
Expenditure on education (% of GDP)



Graduates in science and engineering (% of total graduates)

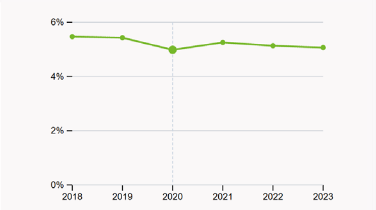


Researchers (FTE per million population)



Gross expenditure on R&D (% of GDP)

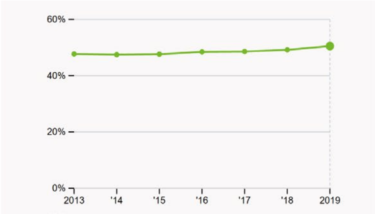
Public research–industry co-publications (% of total publications)



VC received (billion US$)

Domestic industry diversification

Knowledge-intensive employment (% of total employment)



University–industry R&D collaboration

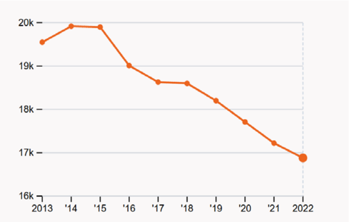
Source: WIPO (2025). Global Innovation Index 2024.

Selected GII 2024 innovation inputs for the UK:

- **Expenditure on education** was equal to 5.4% of GDP in 2021, down by 0.1 percentage points from the previous year – and equivalent to an indicator **rank of 32**.
- **Graduates in science and engineering** was equal to 22.26% of total graduates in 2021, down by 0.49 percentage points from the previous year – and equivalent to an indicator **rank of 64**.
- **Researchers** was equal to 4763.48 FTE per million population in 2019, up by 3.24% from the previous year – and equivalent to an indicator **rank of 24**.
- **Gross expenditure on R&D** was equal to 2.9% of GDP in 2021, down by 0.04 percentage points from the previous year – and equivalent to an indicator **rank of 11**.
- **Public research–industry co-publications** was equal to 5.07% of total publications in 2023, down by 0.07 percentage points from the previous year – and equivalent to an indicator **rank of 13**.
- **Venture capital (VC) received**, value was equal to US$12.41 billion in 2023, down by 34.92% from the previous year – and equivalent to an indicator **rank of 9**.
- **Domestic industry diversification** was equal to an index score of 0.07 in 2021, down by 6.08% from the previous year – and equivalent to an indicator **rank of 2**.
- **Knowledge-intensive employment** was equal to 50.56% in 2019, up by 1.36 percentage points from the previous year – and equivalent to an indicator **rank of 11**.
- **University–industry R&D collaboration** was equal to a survey score of 5.13 in 2023, up by 2.17% from the previous year – and equivalent to an indicator **rank of 11**.

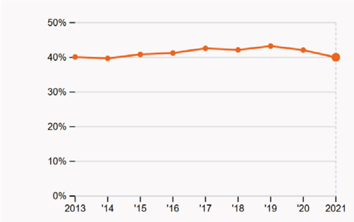
2.3. The UK ranked third in innovation outputs out of 133 economies in the Global Innovation Index (GII) 2024

Patents by origin (total)



Unicorn valuation (% of GDP)

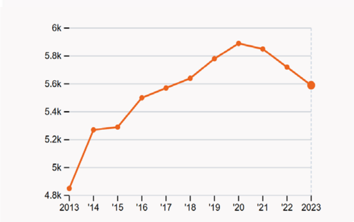
High-tech manufacturing (% of total manufacturing output)



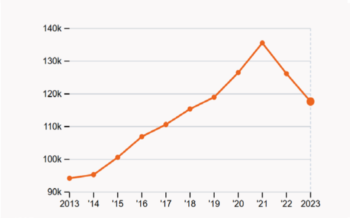
Production and export complexity

High-tech exports (billion US$)

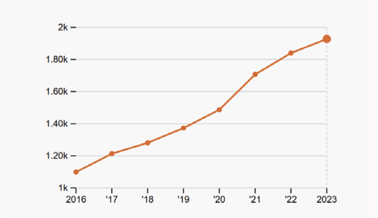
PCT patents by origin



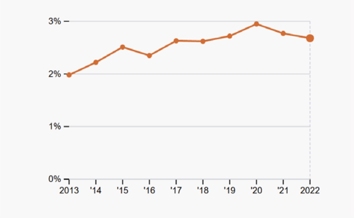
Scientific and technical articles



Citable documents H-index



Intellectual property receipts (% of total trade)



Source: WIPO (2025). Global Innovation Index 2024.

GII 2024 innovation outputs for the UK:

- **Patents by origin** was equal to 16,880 patents in 2022, down by 1.97% from the previous year – and equivalent to an indicator **rank of 16**.
- **Unicorn valuation** was equal to 4.92% of GDP in 2024, down by 0.29 percentage points from the previous year – and equivalent to an indicator **rank of 1**.
- **High-tech manufacturing** was equal to 40.02% of total manufacturing output in 2021, down by 2.08 percentage points from the previous year – and equivalent to an indicator **rank of 26**.
- **Production and export complexity** was equal to a score of 1.61 in 2021, with no change from the previous year – and equivalent to an indicator **rank of 8**.
- **High-tech exports** was equal to US$82.43 billion in 2022, up by 4.99% from the previous year– and equivalent to an indicator **rank of 25**.
- **PCT patents by origin** was equal to 5,590 PCT patents in 2023, down by 2.27% from the previous year – and equivalent to an indicator **rank of 20**.
- **Scientific and technical articles** was equal to 117,670 articles in 2023, down by 6.75% from the previous year – and equivalent to an indicator **rank of 16**.
- **Citable documents H-index** was equal to an H-Index of 1928 in 2023, up by 4.78% from the previous year – and equivalent to an indicator **rank of 1**.
- **Intellectual property receipts** was equal to 2.68% of total trade in 2022, down by 0.09 percentage points from the previous year – and equivalent to an indicator **rank of 8**.

2.4. Numerous opportunities exist for the UK to consolidate its global innovation leadership position by strengthening key innovation system inputs

UK innovation strengths and weaknesses highlighted by WIPO

Category	Strengths		Weaknesses	
	Rank	Indicator name	Rank	Indicator name
Startup/new business	1	Unicorn valuation, % GDP	38	Entrepreneurship policies and
	6	VC recipients, deals/bn PPP$ GDP		
Education and academic research	1	Citable documents H-index	90	Pupil–teacher ratio, secondary
	2	QS university ranking, top three	64	Graduates in science and engineering, %
Investment and R&D	7	Global corporate R&D investors, top three, million US$	35	Research talent, % in businesses
			107	Gross capital formation, % GDP
	4	Intangible asset intensity, top 15, %	72	FDI net inflows, % GDP
Industry	2	Domestic industry diversification	75	Labour productivity growth, %
Service exports	8	Intellectual property receipts, % total trade	52	ICT services imports, % total trade

Innovation input/innovation output, as defined by WIPO

- The UK national innovation system presents a complex landscape, highlighted by the indicators considered in the GII index. For example:
  - While the UK benefits from strong venture capital investment and high unicorn valuations, there is room for improvement in the overall policy ecosystem for entrepreneurship.
  - Despite being home to many world-renowned universities and producing highly cited publications, the UK has a low number of graduates in science and engineering.
  - Although the UK ranks highly in global corporate R&D investment – measured by the average R&D expenditure of its top three global companies – it lags behind in the number of researchers employed in the private sector.
  - Furthermore, despite having a diversified industrial structure in manufacturing, the UK's overall labour productivity growth remains low across the economy.

Source: WIPO (2025). Global Innovation Index 2024.

2.5. At European level, the UK performs particularly well in fostering connections among innovative firms, public and private sectors, and science and technology talent

UK innovation strengths highlighted by the European Innovation Scoreboard

Strengths		
Performance relative to the EU level in 2024	**Indicator name**	**Explanation**
239.2%	**Innovative SMEs collaborating with others**	Number of small and medium-sized enterprises (SMEs) with innovation cooperation activities, including all enterprises that had any cooperation agreements on innovation activities with other enterprises or institutions in the 3 years of the survey period.
219.3%	**Public–private co-publications**	Number of public–private co-authored research publications with both domestic and foreign collaborators. The definition of the "private sector" excludes the private medical and health sector.
193.7%	**Job-to-job mobility of HRST (human resources in science and technology)**	• Human resources in science and technology (HRST) are people who fulfil one or other of the following conditions: 1) they have successfully completed a tertiary level education; 2) they have not formally qualified as above but are employed in an S&T occupation where the above qualifications are normally required. • Job-to-job mobility in this context is defined as the movement of individuals between one job and another from one year to the next. It does not include inflows into the labour market from a situation of unemployment or inactivity. • Mobility of skilled personnel affects the degree of knowledge creation, which is one of the key drivers of innovation.

Source: EU (2024). European innovation scoreboard; EU (2024). European Innovation Scoreboard 2024 Methodology report.

- The UK is a strong innovator, with an overall performance of 114.8% of the EU average in 2024, according to the European Innovation Scoreboard. In particular, the UK's performance is above average for the category of "strong innovators" (111.3% of the EU average). However, the UK's performance is decreasing, compared to 10% growth in the EU between 2017 and 2024.[1]
- The UK's innovation performance benefits from its strong connections between domestic and international innovative firms, the private and public sectors, and science and technology talent.
- The UK also performs well in government support for business R&D, reaching 187.8% of the EU average, including both direct government funding and government tax support for business R&D.[2]

[1] **Source**: EU (2024). European innovation scoreboard.
[2] **Source**: EU (2024). European Innovation Scoreboard 2024 Country Profile United Kingdom.

2.6. Opportunity areas exist in terms of the UK's performance relative to the EU level in areas such as intellectual property (IP) applications and the scale-up of market-facing innovations

UK innovation weaknesses highlighted by the European Innovation Scoreboard

Weaknesses		
Performance relative to the EU level in 2024	**Indicator name**	**Explanation**
33.6%	**Design applications per billion GDP**	Number of individual designs applied for at the European Union Intellectual Property Office (EUIPO).
60.7%	**Sales of new-to-market and new-to-firm innovations as percentage of turnover**	• Sum of total turnover of new or significantly improved products, either new to the enterprise or new to the market, for all enterprises. • The indicator captures both the creation of state-of-the-art technologies (new-to-market products) and the diffusion of these technologies (new-to-enterprise products).

- The UK underperforms against the EU average in intellectual property (IP) applications, including patents, trademarks, and designs, particularly in design applications, which are just 34% of the EU average.
- The UK also lags behind the EU in scaling up market-facing technology, as measured by revenue generated from improved products, whether new to the enterprise or new to the market.

Source: EU (2024). European innovation scoreboard; EU (2024). European Innovation Scoreboard 2024 Methodology report.

2.7. Countries with stronger innovation output performance are typically the ones that allocate a higher proportion of their GDP to R&D expenditure

Performance of UK against other G7 countries and China on selected innovation inputs and outputs

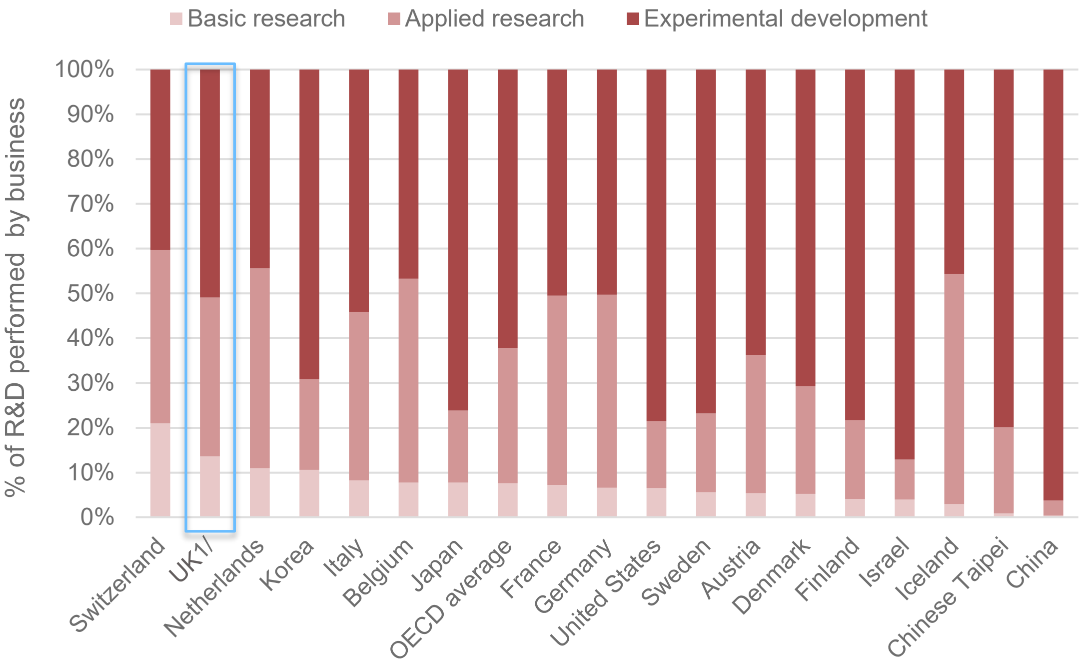
	Selected innovation inputs				Selected innovation outputs			
	Gross domestic expenditure on R&D, as % of GDP, 2022	Higher education expenditure on R&D, as % of GDP, 2022 or latest year	Business enterprise expenditure on R&D, as % of GDP, 2022	Government expenditure on R&D, as % of GDP, 2022	Resident patent applications per US$100 billion GDP (2017 PPP), 2023	Resident design count per US$100 billion GDP (2017 PPP), 2023	Publication per '000 population, 2022	Value added per worker in medium/high-tech manufacturing (PPP), 2021
UK	2.8%	0.7%	2.0%	0.1%	470.5	962	3.5	$178,763
USA	3.6%	0.4%	2.8%	0.3%	1118.7	79.5	2.1	$203,073
Japan	3.4%	0.4%	2.7%	0.3%	3973.8	361.6	1.1	$134,979
Canada	1.7%	0.6%	1.0%	0.1%	183.1	35.3	3.3	$127,084
Italy	1.3%	0.3%	0.8%	0.2%	437	1645.6	2.6	$142,946
France	2.2%	0.5%	1.4%	0.3%	650	933.3	1.8	$195,353
Germany	3.1%	0.6%	2.1%	0.4%	1213.5	830.4	2.4	$169,685
China	2.6%	0.2%	2.0%	0.4%	4875	2575.1	0.7	N.A.

Note: Medium/high-tech manufacturing includes: chemical products; pharmaceuticals; computer and electronics, electrical equipment; machinery and equipment n.e.c.; and automotive and aerospace.
Source: OECD (2024). Main Science and Technology Indicators (MSTI database); ONS (2024). Gross domestic expenditure on research and development, UK: 2022; WIPO. IP Statistics Data Center; DSIT (2022). International comparison of the UK research base, 2022; National Science Foundation (2024). Research and Development: U.S. Trends and International Comparisons; OECD (2024). National Accounts.

- Countries that allocate more of their GDP to R&D expenditure tend to have stronger innovation output.
- But there are notable outliers because of the distinct economic and innovation system structures.
- For example, China, which has the highest number of resident patent applications per US$100 billion of GDP, allocated 2.6% of its GDP to R&D. In contrast, the UK, despite a similar R&D investment as a share of GDP, filed only 10% of patent applications per US$100 billion of GDP relative to China.
- On the other hand, having the largest number of publications per 1,000 people, the UK also allocated the highest share of GDP to R&D performed by higher education among G7 countries and China.

2.8. Business R&D in the UK places greater emphasis on basic research than other leading OECD countries

Share of R&D performed by business (top R&D OECD countries + China and Chinese Taipei), 2017-2021 average, ranked by basic research share

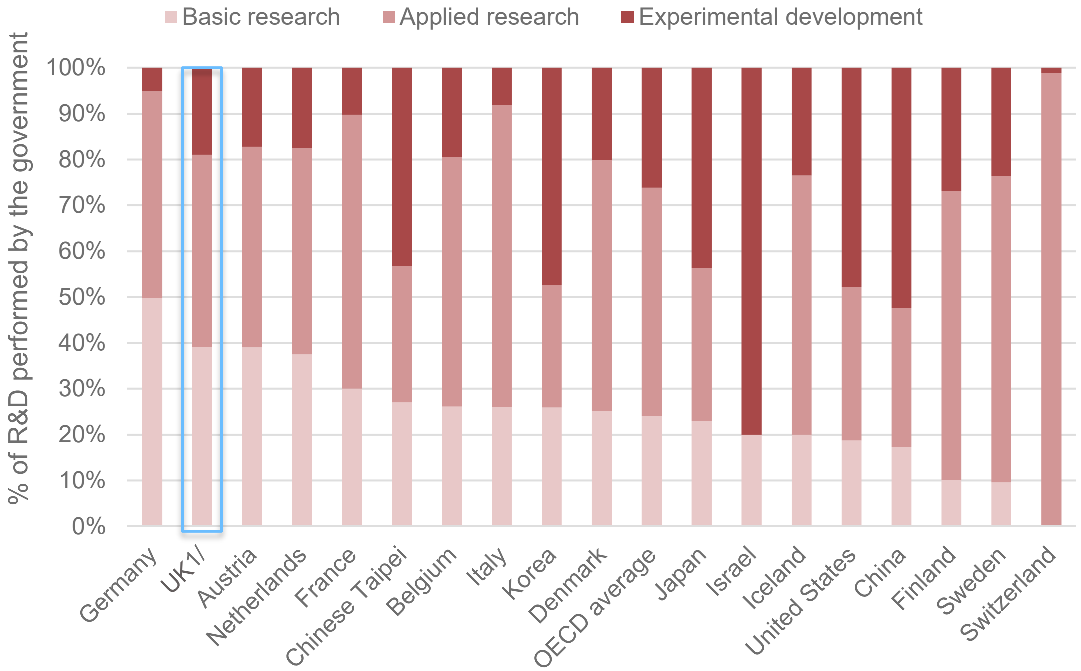


Note: 1/2022 data for the UK.
Source: OECD (2024). Gross domestic expenditure on R&D by sector of performance and type of R&D; ONS (2024). Business enterprise research and development (R&D), UK: 2022.

- OECD BERD data describes different economic and innovation system structures.
- BERD in the UK places greater emphasis on **basic research** (14%) than the average across leading OECD countries (8%), with Switzerland (21%) being the only exception.
- In **applied research** the UK exceeds the average of leading OECD countries (35% compared to 30%). Iceland (51%), Belgium (46%), the Netherlands (45%), and Germany (43%) allocate the highest percentages to applied research.
- In contrast, the UK places less emphasis on **experimental development** (51%) than the top OECD countries (62%). This category of research is predominant in China (96%) and Chinese Taipei (80%). Among OECD nations, Israel (87%), the USA (79%), Finland (78%), and Sweden (77%) report the highest percentages of investment in experimental development.

2.9. Similarly, R&D performed by the UK government also focuses less on experimental development than the average across leading OECD nations

Share of R&D performed by the government (top OECD countries + China and Chinese Taipei), 2017-2021 average, ranked by basic research share



Note: 1/2022 data for the UK.
Source: OECD (2024). Gross domestic expenditure on R&D by sector of performance and type of R&D.

- OECD government expenditure on R&D (GOVERD) data describes different economic and innovation system structures.
- R&D performed by the UK government places a stronger emphasis on **basic research** (39%) than the average of leading OECD countries (24%), with Germany (50%) being the only exception.
- In **applied research** the UK places less emphasis (45%) than comparator OECD nations (50%). Countries with a stronger focus on applied research include Switzerland (99%), Italy (66%), Sweden (67%), and Finland (63%).
- Similarly, the UK allocates a smaller proportion of its R&D to **experimental development** (19%) than OECD leading countries (26%). This type of research dominates in China (52%) and Chinese Taipei (43%). Among OECD nations, the USA (48%), Korea (47%), and Japan (44%) report the highest levels of investment in experimental development.

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SECTION 3

Technology scale-up through spinouts and startups

How effective is the UK at translating research into protected intellectual property and spinouts?

In which technology fields do UK spinouts and startups specialise?

How effective is the UK at retaining value from spinouts and startups?

Section 3 – Key findings (1/4)

KEY FINDINGS

Across numerous indicators, the UK's spinout and startup ecosystem shows notable strengths in creating and commercialising novel technologies, especially in pharmaceuticals, biotechnology, and AI. While only a small proportion (1 in 38) of UKRI-funded research grants leads to formal IP protection, half of these involve private sector collaborations, underscoring the importance of industry partnerships. However, although the UK leads Europe in deep-tech spinout value and high-value startups (unicorns and decacorns), the latter tend to focus on service-oriented sectors such as fintech, enterprise software, and insurance rather than hardware, which is an area of particular success for countries such as the USA and China. In parallel, a considerable portion of UK spinout IPOs and acquisitions occur abroad, highlighting a trend towards overseas exits – often tied to larger capital markets and foreign investors. Interviews with technology spinouts/startups indicate that the UK faces systemic challenges in large-scale commercialisation and manufacturing. Nonetheless, the UK remains Europe's leading environment for the creation of academic spinouts and high-value tech startups.

Research grants and intellectual property (IP)

- **Low but significant rate of IP protection:** 1 in 38 UKRI research grants resulted in formal IP protection (published patent application, granted patent, or trademark registration). Half of these IP-protecting grants involved private sector collaboration, highlighting the importance of industry partnerships in commercialising publicly funded research.
- **Types of IP generated:** 80% of IP resulting from UKRI grants were published patent applications, over 10% became granted patents, and 4% were registered trademarks. This indicates a strong inclination towards patent-based protection among research council grant recipients.
- **Field-specific likelihood of IP:** Medicine, engineering, and biosciences projects (backed by the MRC, EPSRC, BBSRC) are more likely to produce patentable outputs, reflecting the commercial potential in these fields.
- **Spinouts and licensing:** 27% of IP-generating projects formed a spinout company to develop the new technology, while 40% of granted patents/trademarks associated with UKRI research grants were licensed, pointing to active IP commercialisation beyond spinout formation.
- **Leading universities and technology transfer:** The four universities receiving the highest levels of research council funding – and possessing mature technology transfer offices (TTOs) – produced the most patent and trademark outcomes. These institutions are located in the South East, London, and East of England, indicating a regional concentration of high-impact research commercialisation.

Section 3 – Key findings (2/4)

KEY FINDINGS

Spinout sectoral and technological focus: pharmaceuticals, biotechnology, and emerging technologies

- **Dominance of pharmaceuticals and biotechnology:** Pharmaceuticals and biotechnology stand out as the most-used patent technology fields in UK universities and spinouts. Overall, 47% of UK higher education institution (HEI) patent publications fall under chemistry (versus 21% globally), largely because of the heavy focus on pharmaceuticals and biotechnology.
- **Specialisation patterns:** Spinouts exhibit technology field profiles very similar to those of UK HEIs, underscoring a close alignment between academic research and spinout activity. Beyond pharmaceuticals, the UK also shows considerable AI spinout activity, especially among "emerging" technology sectors.
- **Sector variety and growth:** After pharmaceuticals (331 spinouts), research tools and reagents (302 spinouts), analytics, insight, and tools (270 spinouts), and software-as-a-service (144 spinouts) demonstrate significant growth. AI, genomics, and precision medicine are leading "emerging" sectors benefiting from top-tier university research. The UK leads Europe in spinout value, with twice the deep-tech spinout value of Germany, indicating strength in commercialising cutting-edge science and engineering.
- **Deep-tech spinout leadership:** The UK leads Europe, with twice the deep-tech spinout value created as its nearer competitor, Germany (i.e. technology based on tangible engineering innovation or scientific advances and discoveries).

Spinout creation, exits, and geographic trends

- **Concentration in top universities:** Over half (52.3%) of UK spinouts since 2011 have originated from 10 academic institutions, led by Oxford, Cambridge, and Imperial.
- **Exit patterns – acquisitions versus IPOs:** Only 10% of spinouts in the analysed population achieved exits during 2014–23, often leaning towards acquisitions rather than IPOs, potentially because of firms awaiting favourable market conditions for public listing. The majority of UK spinout IPOs since 2012 have occurred overseas (80% in the USA), a reversal from the early 2000s when most listed on UK-based exchanges.
- **Foreign acquisitions:** For spinouts that achieve exit through acquisition, a significant proportion are acquired by foreign companies: ~36% by US-headquartered acquirers and ~24% by European-headquartered acquirers. Approximately one-third are acquired by UK-headquartered businesses, indicating some domestic appetite for acquisitions but dominated by international buyers.
- **Spinout investment deals:** The majority of £100M+ spinout investment deals in the UK include overseas investors only.

Section 3 – Key findings (3/4)

KEY FINDINGS

Venture capital and market focus

- **High overall VC funding, dominance of ICT and biotech/healthcare:** The UK draws the third-largest VC investment in the world and the largest share of VC funding in Europe, but it ranks tenth in deep tech focus within Europe, underscoring a mismatch between high total investment and its concentration in deep tech fields. Fintech, ICT, and biotech/healthcare attracted 57% of VC investment in 2023, implying narrower sector diversification.
- **Software dominance in European venture capital investment:** Just over 20% of European VC funding went to hardware between 2016 and 2023.
- **Investment stages and buyouts:** The UK and Ireland see balanced investment in both startups and later-stage ventures and are second in firm buyout value in Europe. They also support three times more startups than later-stage ventures (in absolute number of firms) and rank third for the total number of firm buyouts – indicating a vibrant, if somewhat acquisition-oriented, ecosystem.
- **UK leadership in European deep-tech VC funding:** The UK received the highest deep-tech VC funding in Europe, followed by France and Sweden, albeit with a lower focus on deep tech than its competitors. Within European countries, Sweden, Switzerland, Hungary, and France have the highest deep tech focus.
- **Startup emigration below European average:** The UK's startup emigration rate (5.9%) is slightly below Europe's average (6%), with 91% going to the USA. Despite the UK being the largest importer of European startups, the country records a net outflow of startups, mostly to the USA. It nonetheless remains Europe's leading hub for spinout creation and high-level VC investment.

High-value startups (unicorns and decacorns)

- **Global ranking and sector bias:** By the end of 2024, the UK ranked fourth globally, with 52 unicorns and 3 decacorns. Unlike global trends (e.g. hardware success in the USA and China), the UK's high-value startups emphasise financial services and enterprise tech, aligning with London's role as a global financial hub.
- **Location and market orientation:** 44 of these high-value startups operate from London, reflecting the capital's central role in supporting advanced services. Industrial or hardware-oriented unicorns are quite rare compared to other major ecosystems worldwide.

Section 3 – Key findings (4/4)

KEY FINDINGS

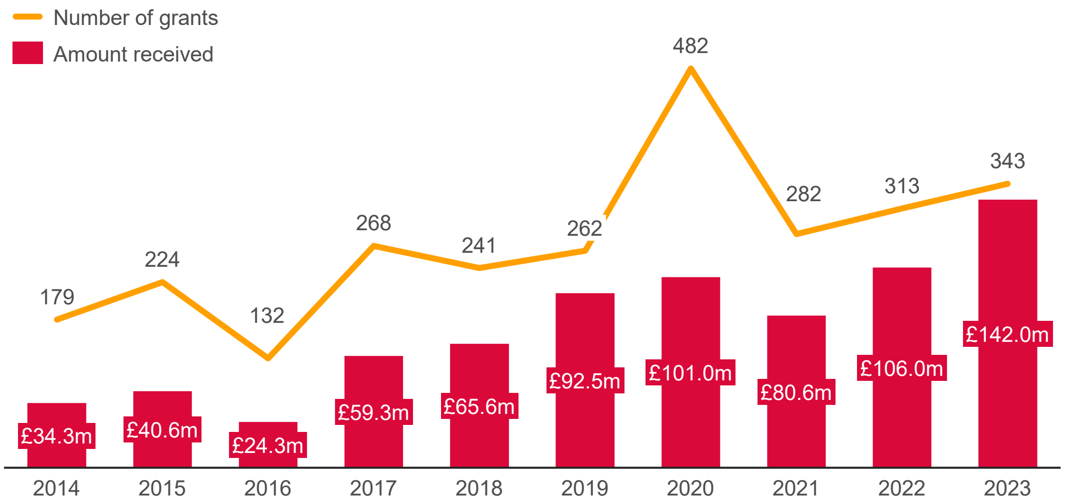
Barriers to scale-up

- A limited sample of spinout/startup interviewees consistently paint a picture of a UK that excels in early-stage innovation and R&D but faces significant systemic challenges in the transition to large-scale commercialisation and manufacturing in sectors outside the dominant ones (i.e. sectors other than pharmaceuticals, biotechnology, and AI/software).
- While the UK boasts an excellent science and innovation base, translating this into large-scale domestic manufacturing and commercialisation is hampered by issues accessing appropriate finance, navigating complex regulatory and policy environments, securing the necessary talent, and a perceived lack of coherent industrial strategy.
- Foreign markets, particularly the USA and Germany, are seen as offering more attractive conditions and incentives for manufacturing and commercialisation.
- While some government initiatives like R&D tax credits and early-stage grants are valuable, others, like catapults, are seen as opportunities for further development.
- Interviewees suggest that the UK needs to address these fundamental challenges to become a more attractive location for technology companies looking to scale up and manufacture domestically. Otherwise, the economic benefits of its strong innovation base risk being realised elsewhere.

Spinouts

3.1. Innovate UK grant funding for spinouts increased fourfold between 2014 and 2023, while grant numbers doubled

Innovate UK grants received by spinouts (2014–23)



2,726
total number of IUK grants (2014–23)

£747m
total value of IUK grants (2014–23)

- Between 2014 and 2023, the value of Innovate UK grant funding awarded to spinouts saw more than a fourfold increase, going from £34.3m to £142m, while the number of grants nearly doubled from 179 to 343.
- Since 2021, there has been an increase in awards and total value each year.
- Spinouts secured 34.0% more investment by value in 2023 than the year before.

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Source: Beauhurst (2024). Spotlight on spinouts April 2024, UK academic spinout trends.

3.2. Only 1 in 38 UKRI research grants chose to protect their resulting IP with a published patent application, granted patent, or trademark registration, with half of these grants done in collaboration with the private sector

UK Research and Innovation (UKRI) self-reported data on research council grants and their outcomes: analysis of 70,152 UKRI research grants awarded to projects that started between 2010 and 2020

- Of the **37,852 research grants** awarded to projects completed by the end of 2020, **1 in 38** chose to protect their resulting IP with a published patent application, granted patent, or trademark registration.
- Of the patent and registered trademark outcomes reported by grant recipients, most were published **patent applications (>80%)**, followed by **granted patents (>10%)** and **registered trademarks (4%)**.

- Scientific research projects in the fields of **medicine, engineering, and biosciences** (funded by the MRC, EPSRC, and BBSRC) were more likely to produce outputs suited to patent protection:
  - **27% of UKRI** research projects that reported a registered patent or trademark outcome reported **creating a spinout company** to take forward these IP assets.
  - **40% of registered patents and trademarks** associated with research council grants were reported as **licensed**.
  - **Almost half (49%)** of UKRI research projects that reported a registered patent or trademark outcome were mostly associated with **private sector collaboration**. Recipients of research council grants between 2010 and 2020 most frequently reported collaborations with **AstraZeneca** (374 collaborations), **GlaxoSmithKline** (320 collaborations), **Rolls-Royce Group** (151 collaborations), **National Biofilms Innovation Centre** (149 collaborations), and **Unilever** (112 collaborations).

- From the data provided, **projects led by the four universities receiving the highest research council grant funding** and largest average grants also **led to the most patent and registered trademark outcomes**. These universities all have mature technology transfer offices (TTOs) – at least 20 years old – and large net current assets. These universities are located in the South East, London, and East of England.

Source: UKIPO (2023). From public research spend to innovation: the role of registered IP.

3.3. Pharmaceuticals and biotech are the most patented technology fields by UK universities and spinouts

Patent applications from 1999 to 2018 split by WIPO technology field

Rank	WIPO technology field	Number of patents 1999–2008	Number of patents 2009–2018	Total
UK HEIs (higher education institutions)				
1	Pharmaceuticals	4,804	5,382	10,186
2	Biotechnology	4,890	4,845	9,735
3	Analysis of biological materials	2,213	2,051	4,264
4	Organic fine chemistry	1,837	2,413	4,250
5	Medical technology	1,716	2,372	4,088
6	Measurement	1,815	2,202	4,017
7	Chemical engineering	1,064	1,361	2,425
8	Computer technology	1,007	1,185	2,192
9	Optics	1,012	961	1,973
10	Basic materials chemistry	751	1,099	1,850
Spinouts				
1	Pharmaceuticals	260	2,283	2,543
2	Biotechnology	352	1,928	2,280
3	Measurement	252	1,064	1,316
4	Organic fine chemistry	113	1,189	1,302
5	Medical technology	176	872	1,048
6	Computer technology	154	797	951
7	Chemical engineering	88	721	809
8	Electrical machinery, apparatus, energy	67	738	805
9	Analysis of biological materials	166	625	791
10	Basic materials chemistry	75	509	584

- In 2008, WIPO defined 5 technology sectors, subdivided into 35 broad technology fields, to categorise all patents depending on where they are classified under the International Patent Classification (IPC) scheme.
- **47% of UK HEI patent publications are in the chemistry sector**, compared with 21% of all patent applications globally.
- The tendency to publish in the chemistry sector is largely accounted for by UK HEIs patenting heavily in the **pharmaceuticals** and **biotechnology** field.
- The technology fields that spinouts tend to publish patents in are **very similar to those of UK HEIs**, suggesting a strong specialisation.

Source: UKIPO (2020). IP filing habits of UK Higher Education Institutions.

3.4. Pharmaceuticals make up the largest number of UK spinouts, whereas AI is the largest sector outside traditional classifications

1,880 total number of UK spinouts tracked by Beauhurst since 2011

Top sectors by number of spinouts (Jan 2024)

Rank	Sector	Number of spinouts
1	Pharmaceuticals	331
2	Research tools and reagents	302
3	Analytics, insight, tools	270
4	Clinical diagnostics	173
5	Cleantech	162
6	Software-as-a-service (SaaS)	144
7	Medical devices	139
8	Materials technology	114
9	Mobile apps	78
10	Internet platform	76
11	Nanotechnology	70
12	Medical instrumentation	66
13	Security services (physical and virtual)	60
14	Educational services	52
15	Healthcare products	51
16	Desktop software	48
17	Chemicals	47
18	Electrical components	41
19	Waste management services	36
20	Semiconductors	35

Top emerging sectors by number of spinouts (Jan 2024)

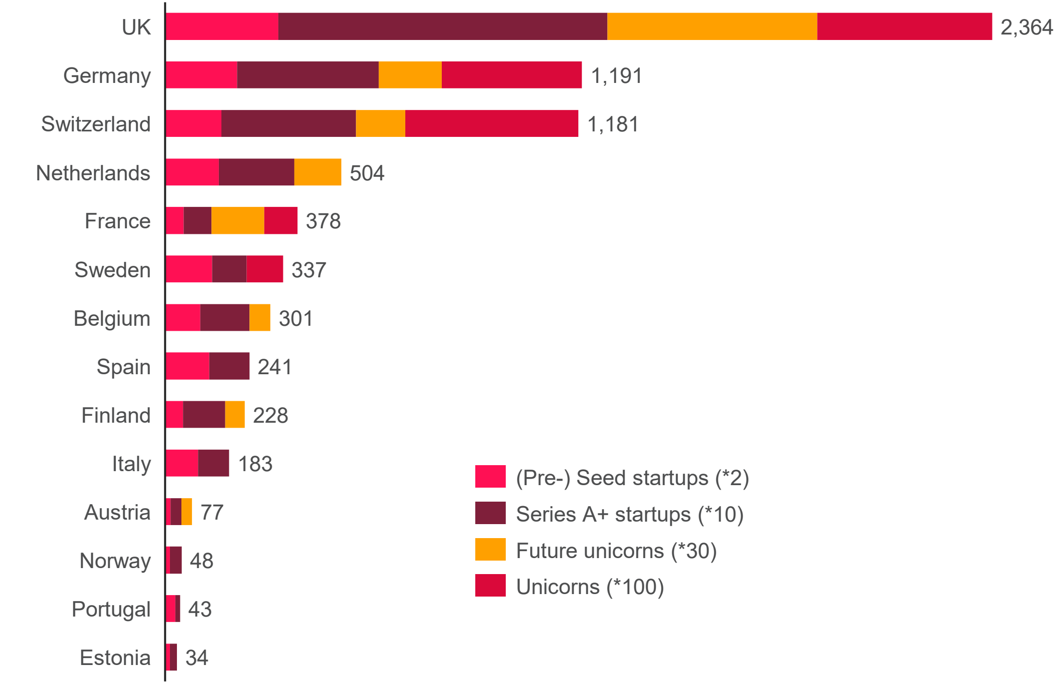
Rank	Emerging sector	Number of spinouts
1	Artificial intelligence	184
2	Genomics	101
3	Precision medicine	94
4	eHealth	60
5	Big data	45
6	Digital security	44
7	Wearables	41
8	Internet of things	40
9	Regenerative medicine	37
10	Edtech	28
11	3D printing	27
12	Graphene	26
13	Virtual reality	24
14	Quantum	22
15	Synthetic biology	21
16	Augmented reality	19
17	Robotics	17
18	Cloud computing	17
19	Image and voice recognition	16
20	Preventive care	15

- Based on Beauhurst data, the pharmaceuticals sector, focused on drug discovery and development, continues to lead, with 331 companies.
- This is followed by the research tools and reagents sector, which has 302 companies that supply specialised machinery and reagents such as antibodies and DNA for scientific experiments.
- Analytics, insight, and tools (270), paired with the software-as-a-service (SaaS) sector (144), underscore the continued demand for data-driven decision-making and cloud-based software solutions.
- Cleantech encompasses firms focused on clean energy, efficiency tech, and other clean technology.
- Emerging sectors are areas of technological innovation and application outside existing sector classifications.
- The AI industry (184) dominates the emerging sector list, followed by genomics (101) and precision medicine (94), which fall under life sciences and benefit from the research conducted by top-tier universities.

Source: Beauhurst (2024). Spotlight on spinouts April 2024, UK academic spinout trends.

3.5. The UK leads Europe, with twice the deep-tech spinout value created as its nearer competitor

Dealroom data, 2023 – university value creation is ranked by multiplying the number of spinouts at every stage of maturity for a score of 2 (for a VC-backed spinout) to a score of 100 (for a unicorn)



- Dealroom.co is a global provider of data and intelligence on startups and tech ecosystems.
- It classifies deep tech startups as those whose technology is based on tangible engineering innovation or scientific advances and discoveries applied for the first time as a product, often aiming to solve society's biggest issues.
- Dealroom estimates that, over the next 5 years, 60% of revenue in "technology" will come from hardware, with only 40% coming from software. In contrast, slightly over 20% of VC funding has gone to hardware since 2016.
- Example deep tech areas include:
    - quantum computing
    - health technologies (e.g. drug development, synthetic biology)
    - space technologies (e.g. launch vehicles in space operations)
    - photonics technologies
    - climate technologies (e.g. hydrogen, CCS, nuclear fission and fusion)
    - AR and VR
    - blockchain infrastructure
    - artificial intelligence
    - semiconductors
    - other defence technologies

Source: Dealroom (2023). The 2023 European Deep Tech report.

3.6. Over half of UK spinouts created since 2011 originated from 10 academic institutions, while only 10% achieved exits through IPOs or acquisitions

Top academic institutions by total number of spinouts tracked by Beauhurst since 2011 (January 2024)

Rank	University	Number of spinouts
1	University of Oxford	210
2	University of Cambridge	149
3	Imperial College London	124
4	University College London	93
5	University of Manchester	86
6	University of Bristol	76
7	Royal College of Art	72
8	University of Edinburgh	66
9	Swansea University	57
10	Queen's University Belfast	56
11	University of Strathclyde	48
12	University of Warwick	47
13	Falmouth University	46
14	University of Sheffield	45

Of the 1,880 university spinouts in the UK, **355 (18.9%)** have ceased operations.

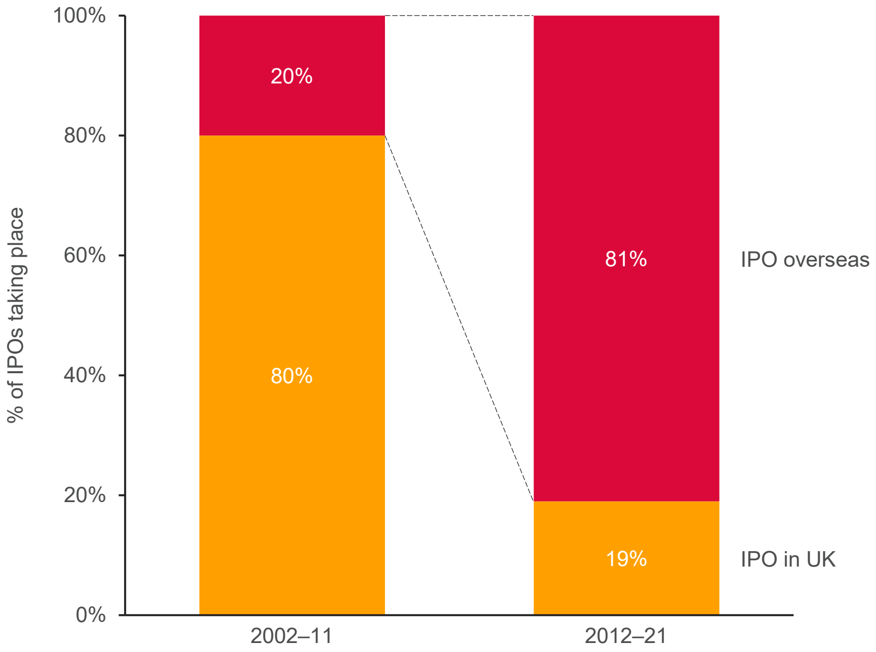
Between 2014 and 2023, a total of **188 spinouts achieved successful exits (10%)**, 30 via IPO and 158 via acquisition.

- 52.3% of spinouts originated from the top 10 academic institutions.
- The University of Oxford remains the leading institution in terms of spinout creation, with its number of spinouts increasing from 205 to 210 over the last year.
- The University of Cambridge continues to hold the second spot, with its total spinout count increasing from 145 to 149.
- Imperial College London experienced the most significant growth in spinout numbers, with a 14.8% increase, raising its total from 108 to 124.
- The trend towards acquisitions over IPOs may be due to companies opting to delay going public, possibly anticipating more favourable market conditions.

Source: Beauhurst (2024). Spotlight on spinouts April 2024, UK academic spinout trends.

3.7. The majority of UK spinout IPOs happen overseas

Location of initial public offerings (IPOs) of UK spinouts for different time periods

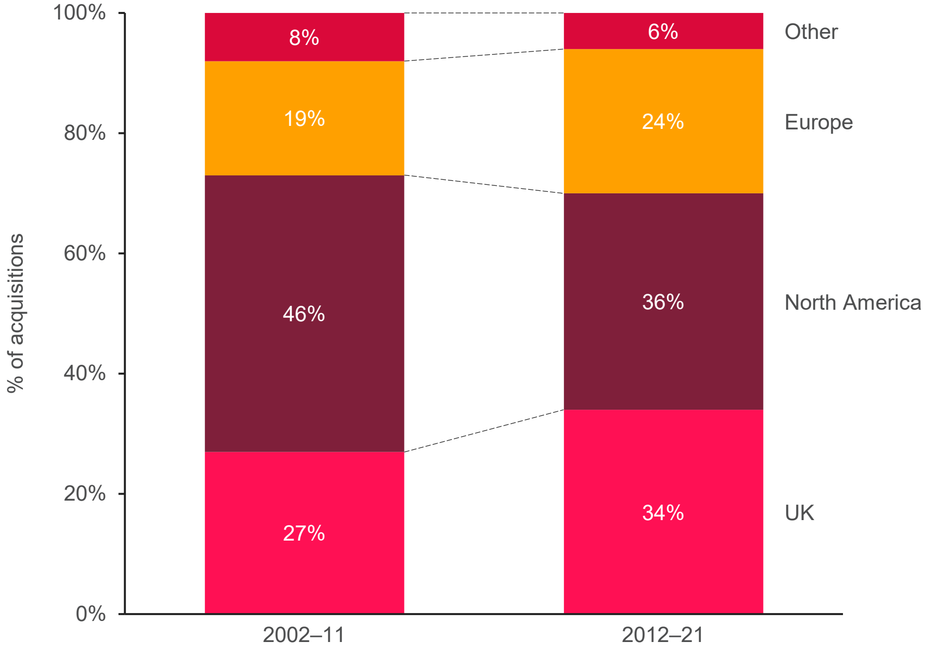


- The University Commercialisation and Innovation (UCI) unit at the University of Cambridge collected data from 884 spinouts across 15 top UK universities.
- Using this sample, the report leveraged information provided by PitchBook and other sources to identify whether these spinouts had listed on a stock exchange, identifying where it (first) listed globally. A total of 36 IPOs (4%) were reported in the data sample.
- Results show that during the early period, 2002–11, 80% of spinout IPOs took place on UK-based stock exchanges.
- This reverses for the more recent period, 2012–21, with 80% of IPOs taking place overseas (the majority on the US NASDAQ).

Source: Roupakia, Z. and Coates Ulrichsen, T. (2025). *Universities and the Spinout Scale-Up Challenge: Securing Value in a Changing World*. Apollo - University of Cambridge Repository.

3.8. The majority of UK spinout acquirers are from abroad

Location of the acquirer's headquarters for UK-based spinouts founded in different time periods that have been acquired

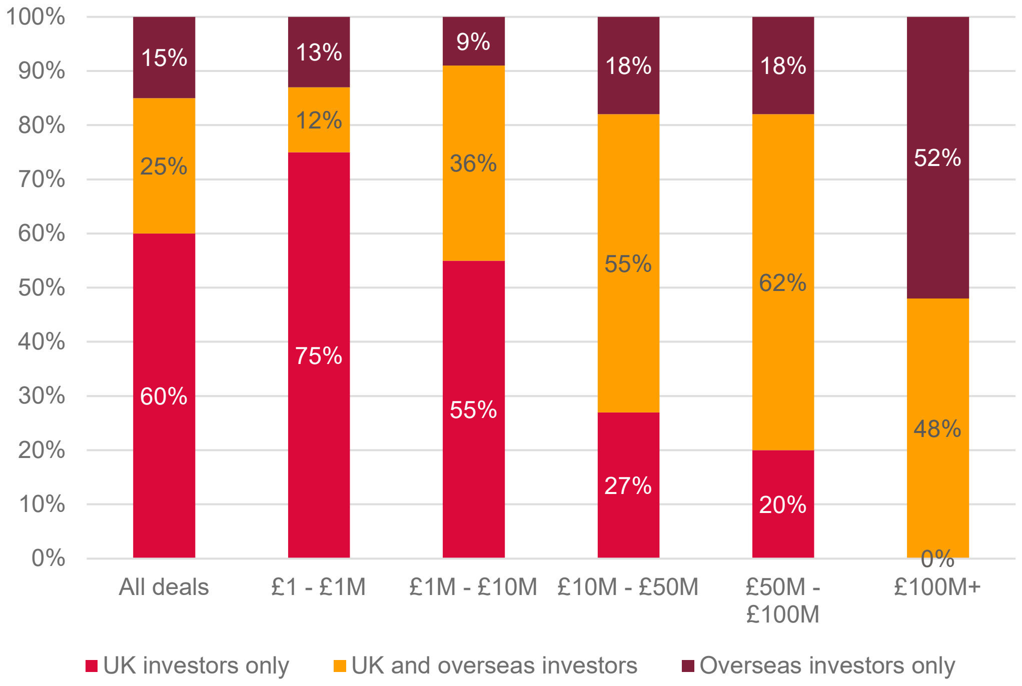


- The University Commercialisation and Innovation (UCI) unit at the University of Cambridge collected data from 884 spinouts across 15 top UK universities.
- Using this sample, the report leveraged information provided by PitchBook and other sources to identify whether these spinouts had listed on a stock exchange, identifying where it (first) listed globally. A total of 117 acquisitions (13%) were reported in the data sample.
- For the 10 years from 2012 to 2021, roughly a third of acquisitions of spinouts from the 15 universities that participated in the study were by UK-headquartered companies.
- A further 36% were acquired by US-headquartered companies, and 24% by European-headquartered companies.

Source: Roupakia, Z. and Coates Ulrichsen, T. (2025). *Universities and the Spinout Scale-Up Challenge: Securing Value in a Changing World*. Apollo - University of Cambridge Repository.

3.9. The majority of £100M+ spinout investment deals in the UK include overseas investors only

Locational composition of investors (based on investor headquarters) involved in spinout deals of different sizes for spinouts founded between 2012 and 2021



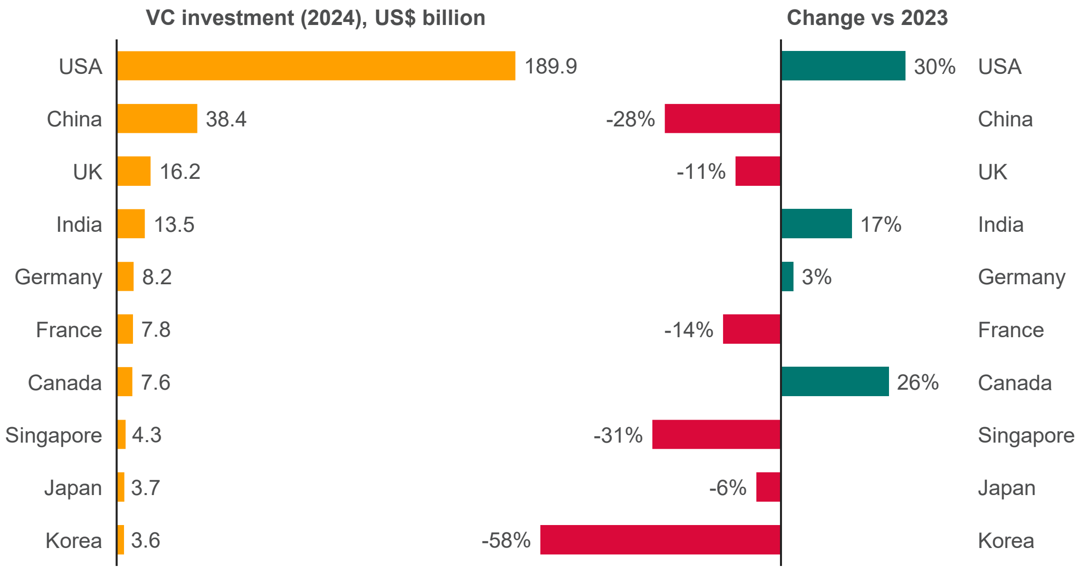
- The University Commercialisation and Innovation (UCI) unit at the University of Cambridge collected data from 884 spinouts across 15 top UK universities.
- Using this sample, they focus on spinouts founded between 2012 and 2021, represented in PitchBook, for which both deal and investor information was available. This allowed the progression of deals to be examined as spinouts grow and scale, and how the location of investors shifts for deals of different sizes. The investor location is determined by the investor headquarters.
- This data shows that for smaller deals (up to £1 million and excluding grants), the majority of deals (75%) were driven by UK-based investors. As deal sizes increased, many more deals began to involve overseas investors. For deals up to £100 million, this happened alongside UK-based investors. For the largest deals (above £100 million), just over half of the deals identified were driven by overseas investors alone, while the rest were a mix of UK and overseas investors.

Source: Roupakia, Z. and Coates Ulrichsen, T. (2025). *Universities and the Spinout Scale-Up Challenge: Securing Value in a Changing World*. Apollo - University of Cambridge Repository.

Startups

3.10. The UK's startup ecosystem ranks third globally in terms of VC investment raised, a position it has maintained since 2019, with the exception of 2021

Countries by venture capital (VC) investment, 2024 and change versus 2023

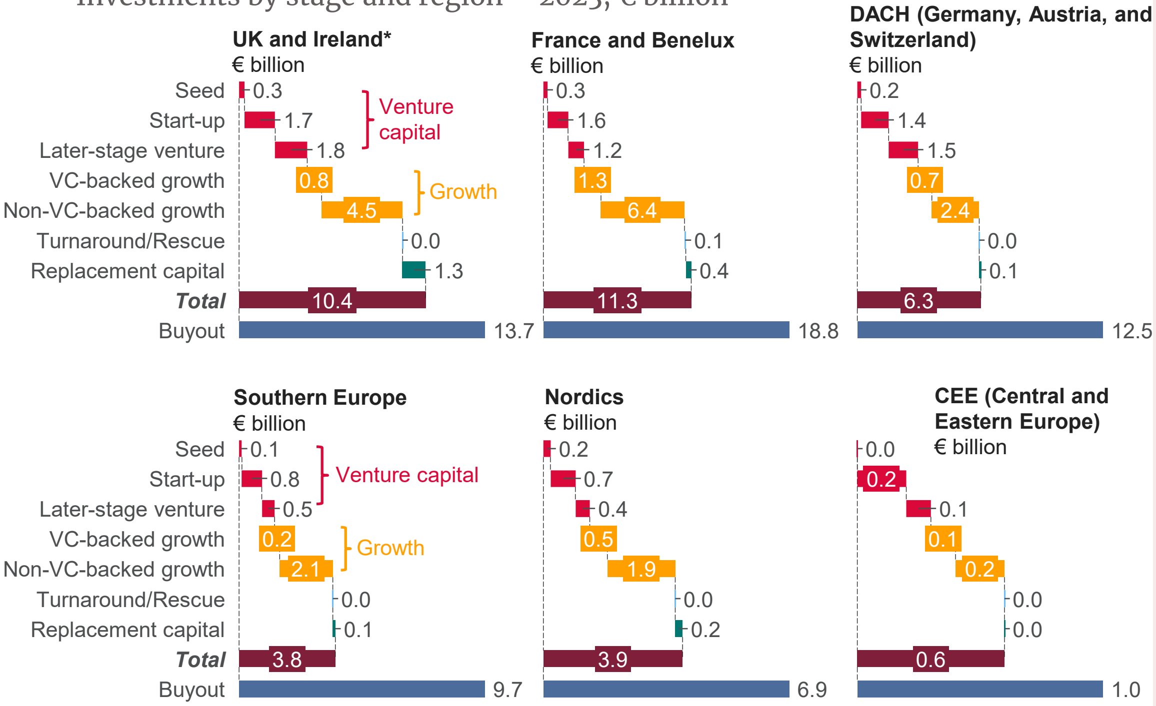


- Not only is the UK the third VC ecosystem globally, it has also consistently led the European continent by a large margin, followed by Germany with US$8.2 billion in 2024.
- London ranks as the number 1 funded tech ecosystem in Europe, ahead of Paris and Munich.

Note: Original values in euros, converted at the annual average nominal exchange rate.
Source: Dealroom (2025). United Kingdom.

3.11. UK and Ireland venture capital was evenly invested in startups and later-stage ventures in 2023, while they had the second-largest firm buyout value in Europe

Investments by stage and region – 2023, € billion



- In 2023 the largest share of venture capital investments in the UK and Ireland was directed at later-stage ventures, in line with comparator countries such as Germany, Austria, and Switzerland, but different to France, Belgium, the Netherlands, Luxemburg, and other European regions.
- In terms of buyout value, the UK and Ireland ranked second in Europe, after France and the Benelux region (i.e. Belgium, the Netherlands, and Luxemburg).

***Note:** Ireland represents 5.6% of total UK venture-capital investment.
Source: Invest Europe (2024). Investing in Europe: Private Equity Activity 2023.

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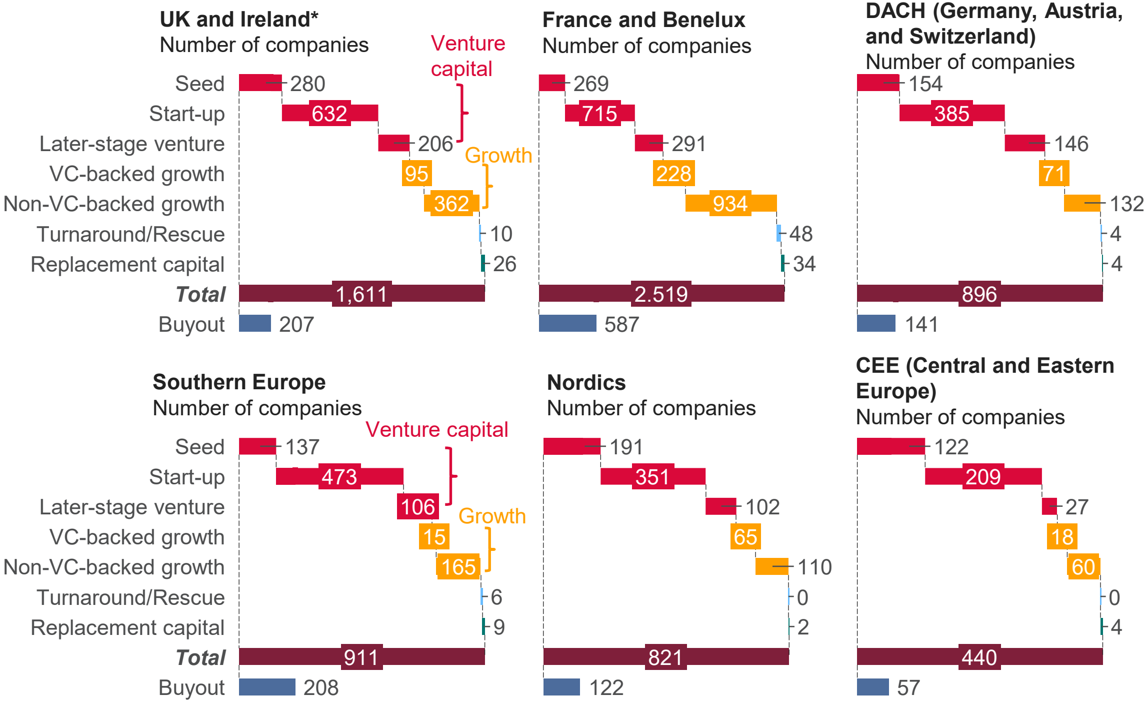
Cambridge Industrial Innovation Policy

3.12. UK and Ireland venture capital supported three times more startups than later-stage ventures in 2023, while having the third-largest number of firm buyouts in Europe

Investments by stage and region – 2023, number of companies



- In 2023 the largest share of firms supported through venture capital investments in the UK and Ireland were startups, in line with comparator regions.
- The UK and Ireland had the third-largest number of firm buyouts in Europe in 2023.

Note: Ireland represents 5.6% of total UK venture-capital investment.
Source: Invest Europe (2024). Investing in Europe: Private Equity Activity 2023.

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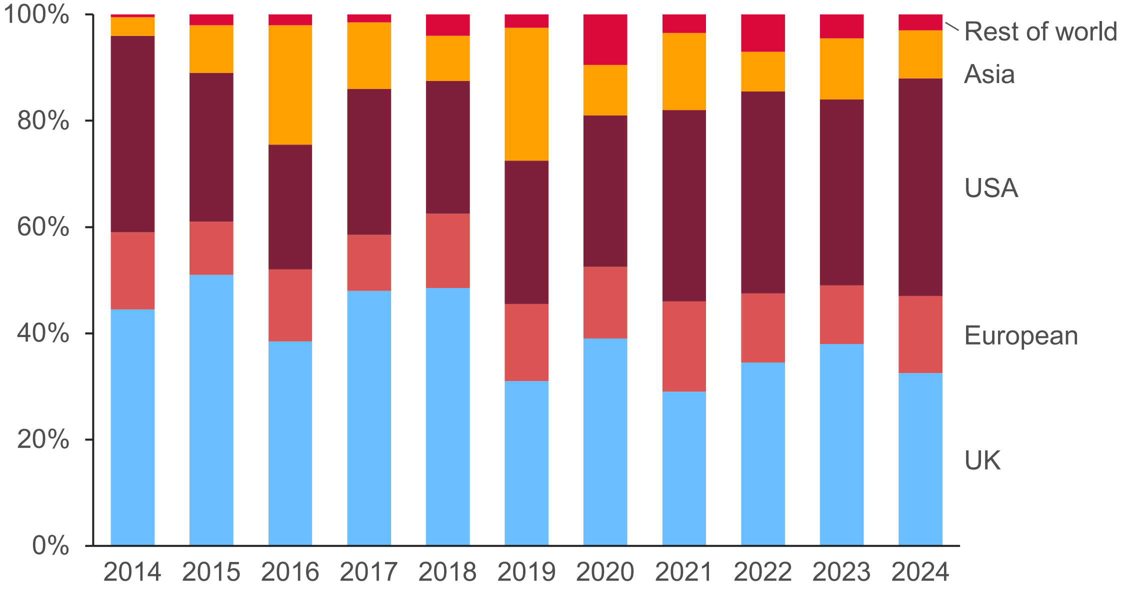
3.13. In 2024, 68% of UK VC investment came from foreign sources, with 41% coming from the USA

UK global venture capital by sources of capital, 2014-2024



- Foreign investors play a key role in the UK venture capital market, with over half of VC investment coming from sources outside Europe, such as the USA and Asia.
- The UK is the centre of the European venture capital market, home to 40% of the continent's venture capital.

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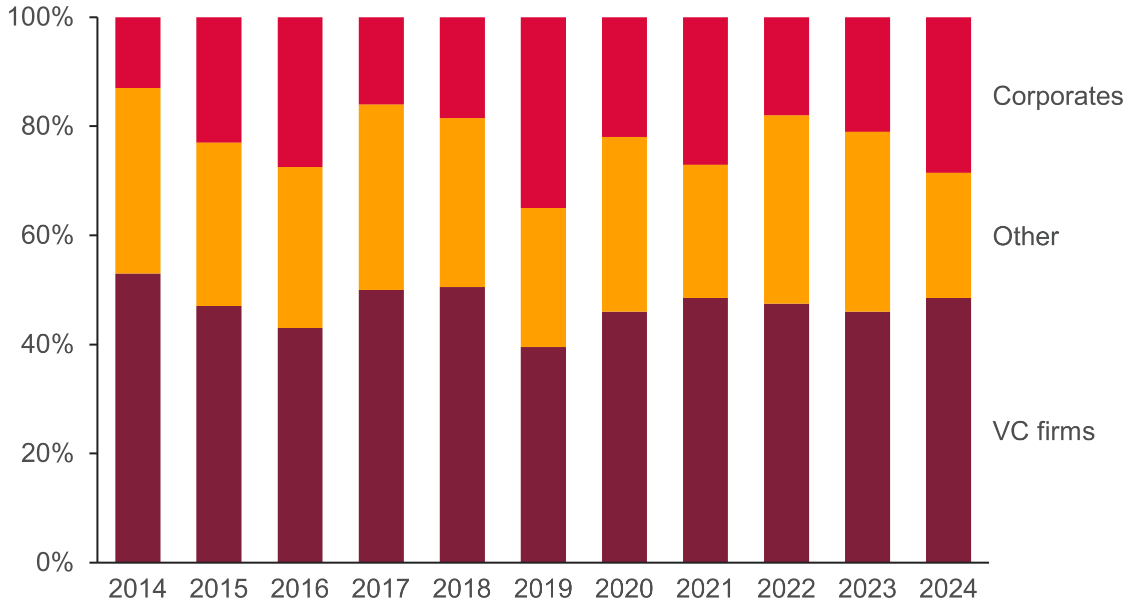
Source: Dealroom (2025). United Kingdom.

3.14. In 2024, 28% of UK venture capital originated from corporate businesses

UK venture capital by source, 2014-2024



- Over the past decade, VC firms have consistently made up between 40% and 50% of the total funding of the UK startup ecosystem.
- Other sources of VC investment in the UK come from corporates, private equity firms, and angel investors, among others.

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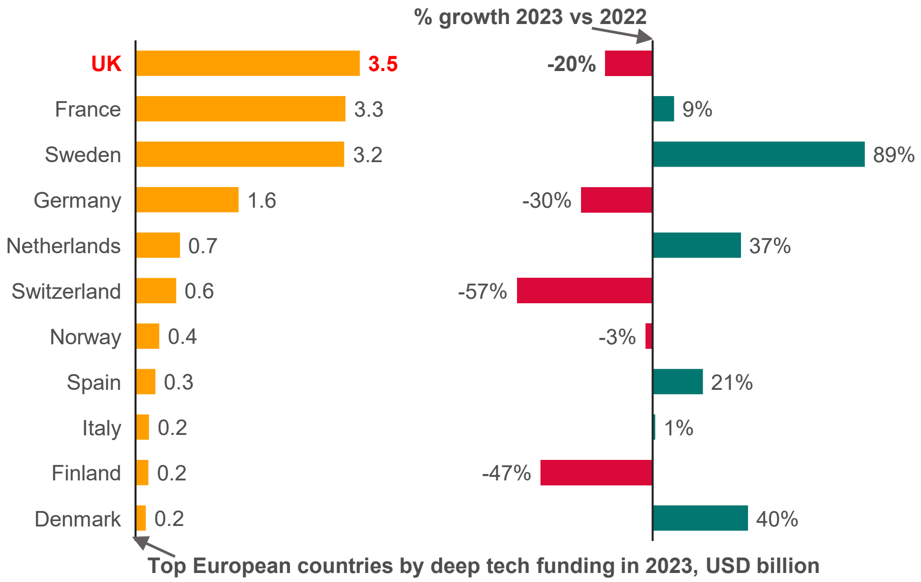
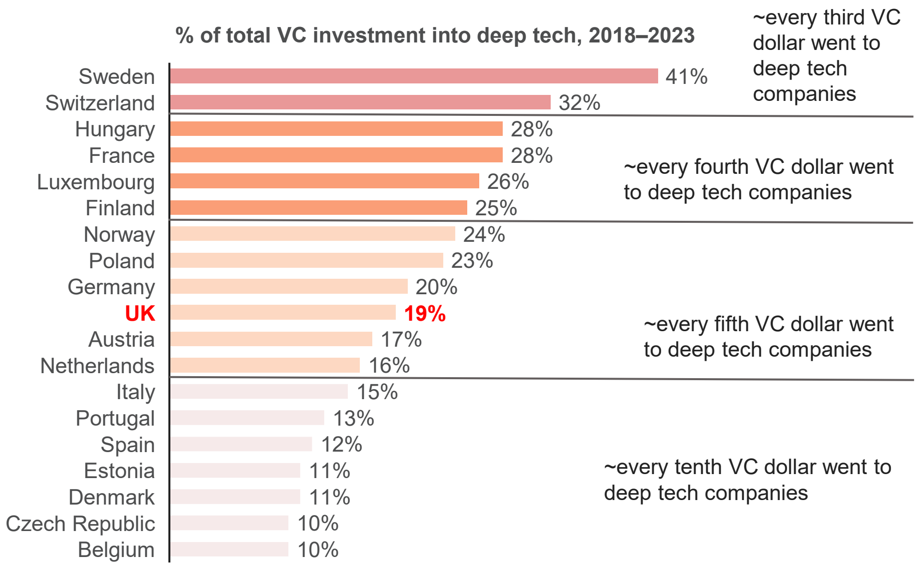
Source: Dealroom (2025). United Kingdom.

3.15. The UK attracted the highest value of deep-tech VC funding in Europe, ahead of France and Sweden, though deep tech accounted for a smaller share of total VC investments than some competitors



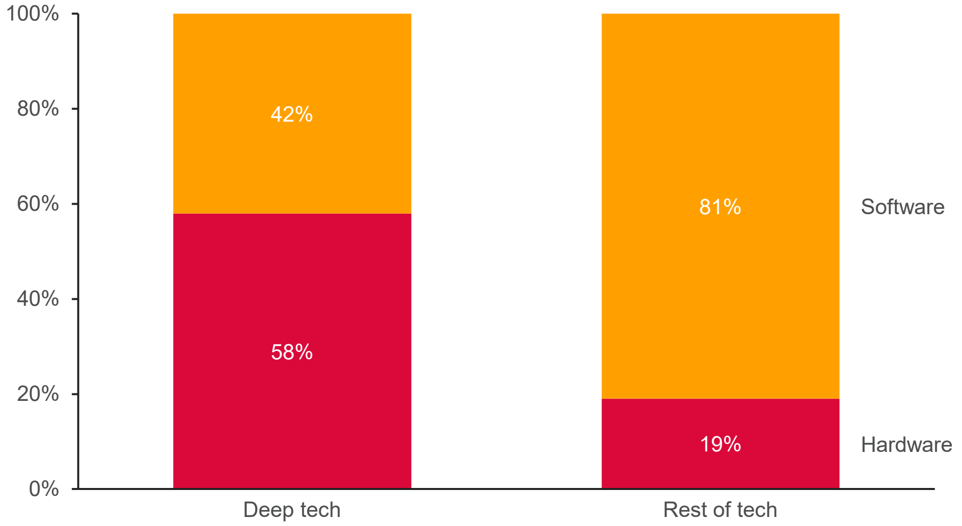


Note: Dealroom.co is a global provider of data and intelligence on startups and tech ecosystems. It classifies deep tech startups as those whose technology is based on tangible engineering innovation or scientific advances and discoveries applied for the first time as a product, often aiming to solve society's biggest issues. Example deep tech areas include: quantum computing; health technologies (e.g. drug development, synthetic biology); space technologies (e.g. launch vehicles in space operations); photonics technologies; climate technologies (e.g. hydrogen, CCS, nuclear fission and fusion); AR and VR; blockchain infrastructure; artificial intelligence; semiconductors; and other defence technologies.

Source: Dealroom (2023). The 2023 European Deep Tech report.

3.16. Hardware-related startups receive nearly 60% of European deep-tech VC funding, compared to less than 20% across the rest of the tech startup ecosystem

European VC funding 2016-2023, hardware vs software



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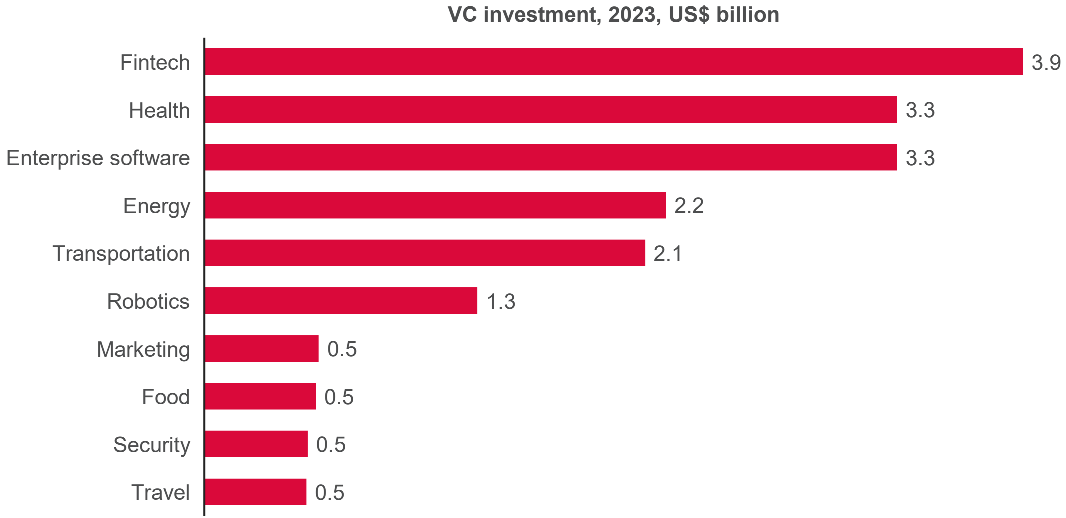
- Dealroom estimates that, over the next 5 years, 60% of revenue in "technology" will come from hardware, with only 40% coming from software. In contrast, just over 20% of VC funding has gone to hardware since 2016.
- Although not all deep tech is hardware (e.g. AI, blockchain, AR/VR, quantum computing software), deep tech is more hardware-oriented than the rest of the venture-capital-backed technology domains.

Source: Dealroom (2023). The 2023 European Deep Tech report.

3.17. Software-driven sectors, by contrast, draw the majority of UK VC investment, with fintech, health, and enterprise services leading the way

UK leading industries by VC investment, 2023



Note: Dealroom.co is a global provider of data and intelligence on startups and tech ecosystems. It classifies deep tech startups as those whose technology is based on tangible engineering innovation or scientific advances and discoveries applied for the first time as a product, often aiming to solve society's biggest issues. Example deep tech areas include: quantum computing; health technologies (e.g. drug development, synthetic biology); space technologies (e.g. launch vehicles in space operations); photonics technologies; climate technologies (e.g. hydrogen, CCS, nuclear fission and fusion); AR and VR; blockchain infrastructure; artificial intelligence; semiconductors; and other defence technologies.

- The UK venture capital market is dominated by three key sectors.
- In 2023 fintech accounted for US$3.9 billion in capital raised, while health (i.e. biotech products and services, medical equipment and devices, pharmaceutical and drug delivery) and enterprise software (i.e. business-related software, computer and data services, internet technologies, hardware, telecommunication services) accounted for US$3.3 billion each.
- This is equivalent to 57% of all the venture capital investments in 2023.

Source: Dealroom (2025). United Kingdom.

3.18. At the end of 2024, the UK was the fourth country in the world in terms of high-value startups, with 52 unicorns and 3 decacorns

Number of high-value startups in the world, 2011-2024

Country ranked by number of high-value startups (over US$1 billion)	Number of startups valued at over US$1 billion
USA	690
China	162
India	68
UK	**55**
Germany	31
France	28
Israel	23
Canada	21
Brazil	18
Singapore	15
Korea	13
Australia	9
Netherlands	9
Mexico	8
Japan	8
Other countries	100
Total	1,258

- Unicorns are startups with a valuation between US$1 billion and US$10 billion.
- At the end of 2024, 1,258 startups worldwide were valued at over US$1 billion, of which 43 were decacorns (valued between US$10 billion and US$100 billion) and 3 were hectocorns (valued at over US$100 billion).[1]
- The USA has 690 high-value startups (54.8% of total world), followed by China (162 startups; 12.9% of total) and India (68 startups; 5.4% of total).
- The UK was the fourth country in the world in terms of high-value startups in 2024, with 52 unicorns and 3 decacorns.
- Enterprise tech, software services for business, and financial services accounted for 51% of sector activities of high-tech startups in the world.

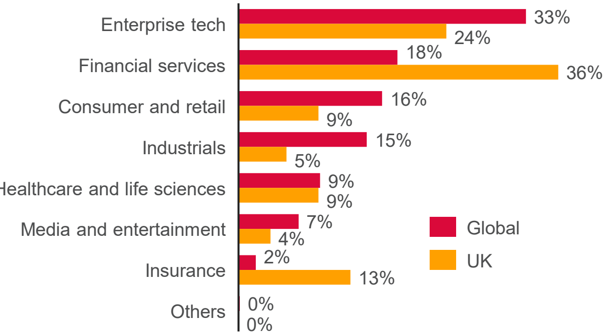
Source: CBINSIGHTS (2025). The Complete List Of Unicorn Companies.

[1] **Source**: CBINSIGHTS (2025). The Complete List Of Unicorn Companies.

3.19. Most successful UK high-value startups are not spinouts and tend to be concentrated in financial services and insurance, with less emphasis on hardware

High-value startup distribution by industry and UK location, 2024

High-value startup distribution by industry



Industry	Example startups
Enterprise tech	OpenAI
Financial services	Stripe
Consumer and retail	SHEIN
Industrials	SpaceX
Healthcare and life sciences	Devoted Health
Media ad entertainment	ByteDance
Insurance	Howden Group Holdings

UK-based high-value startups and locations

London		Peterborough
Revolut	Quantexa	BGL Group
Global Switch	Multiverse	**Cambridge**
Checkout.com	Gousto	CMR Surgical
Rapyd	5ire	**Colchester**
SumUp	Paddle	Accelerant
Blockchain.com	Tripledot	**Altrincham**
Monzo	Motorway	Matillion
Howden	Marshmallow	**Solihull**
ZEPZ	Zego	Gymshark
OakNorth Bank	The Bank of London	**Bristol**
Lendable	Lighthouse	OVO Energy
Greensill	Flo Health	**Aberdeen**
eToro	Huma	BrewDog
Improbable	Beamery	**Manchester**
Thought Machine	Stability AI	Castore
Starling Bank	PPRO	**Gloucester**
ManyPets	Teya	Spectrum Medical
GoCardless	Augustinus Bader	**Crewe**
Synthesia	Tractable	Radius Payment Solutions
PayFit	TrueLayer	**Oxfordshire**
BeZero	Zopa	IntraBio
Zilch	Payhawk	

Source: CBINSIGHTS (2025). The Complete List Of Unicorn Companies.

- Being the fourth country in the world, the UK had 55 high-value startups (including 3 decacorns) by the end of 2024.
- The sectors with more high-value startups are financial services (20 companies), enterprise tech (13 companies), and insurance (7 unicorns each).
- On the other hand, the UK's high-value startups place less emphasis on industrial sectors. Compared to industry-focused startups in competitor countries – such as SpaceX in the USA and DJI in China – the UK's industrial startups are more service-oriented, exemplified by companies like OVO Energy and Motorway, an online second-hand car sales platform.[1]
- As per the venture capital investments in recent years, most of the high-value startups (44) are headquartered in London.
- The UK's startup ecosystem is also home to a further five "exited" unicorns (i.e. sold to larger corporates or admitted to a public stock exchange). Two of them were eventually acquired by Chinese and USA investors.[2]

[1] **Source:** CBINSIGHTS (2025). The Complete List Of Unicorn Companies.
[2] **Source**: Beauhurst (2019). UK Unicorn companies – a free report on £1b businesses.

3.20. The UK's startup emigration share (5.9%) is below the European average (6%), with 91% of migrating firms going to the USA

Startup headquarter relocation patterns for 11,000 VC-backed startups across 17 European countries (2000-14)

Startup headquarter relocation patterns, distribution of startups by country

	Startup HQ location at start																	
	AT	BE	CH	DE	DK	ES	FI	FR	GB	IE	IT	NL	NO	PL	PT	RU	SE	
Final startup HQ location																		**Total (final startup HQ location)**
AT	117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117
BE	0	218	0	2	0	0	0	0	1	0	0	1	0	0	0	0	0	222
CH	0	0	282	1	0	0	1	1	2	0	1	0	0	0	0	0	1	289
DE	1	0	1	1313	0	1	1	2	0	0	0	0	1	0	0	0	0	1,320
DK	0	0	1	0	333	0	0	0	0	0	0	0	0	0	0	0	0	334
ES	0	0	0	0	0	576	0	1	1	0	0	0	0	0	0	0	0	578
FI	0	0	0	0	0	0	367	0	0	0	0	0	1	0	0	0	1	369
FR	0	0	0	0	0	0	0	2072	0	0	0	0	0	0	0	0	0	2,072
GB	1	1	3	1	2	4	4	4	3017	2	2	0	0	0	1	1	5	3,048
IE	0	0	0	1	0	0	0	1	0	299	0	0	0	0	0	0	0	301
IT	0	0	0	0	0	0	0	0	0	0	277	0	0	0	0	0	0	277
NL	0	1	0	0	0	1	0	0	1	0	0	333	1	0	0	1	0	338
NO	0	0	0	0	0	0	0	0	1	0	0	0	205	0	0	0	2	208
Other	1	2	2	4	2	0	4	3	8	0	3	2	0	0	0	1	0	32
PL	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	61
PT	0	0	0	0	0	0	0	0	1	0	0	0	0	0	65	0	0	66
RU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	184	0	184
SE	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	686	689
US	7	13	11	50	24	24	22	95	174	31	10	20	11	6	8	27	28	561
Total (startup HQ location at start)	127	235	300	1373	361	606	400	2179	3206	332	293	356	220	67	74	214	723	11,066
Relocating HQ (%)	7.9	7.2	6	4.4	7.8	5	8.3	4.9	5.9	9.9	5.5	6.5	6.8	9	12.2	14	5.1	6
Relocating to USA (%)	5.5	5.5	3.7	3.6	6.6	4	5.5	4.4	5.4	9.3	3.4	5.6	5	9	10.8	12.6	3.9	5.1

Source: Weik, S., Achleitner, A. K. and Braun, R. (2024). Venture capital and the international relocation of startups.

3.21. A strong domestic startup ecosystem helps to retain startups locally, whereas foreign VC investment often encourages startups to relocate closer to the origin of the investment

➢ **International startup relocation is relatively common**: about 6% of startups move across borders, representing 17% of the total startup value created.

Countries with the fewest startups have the highest emigration rates:

- The three countries with the fewest startups in the sample – Russia (14.0%), Portugal (10.7%), and Poland (9.0%) – have the highest migration rates (in parentheses).
- The three countries with the largest startup populations in the sample – the UK (5.8%), France (4.8%), and Germany (4.3%) – have below-average migration.

Most relocations (85%) are directed to the USA:

- All 17 countries in the sample record a net outflow of startups. Even the UK, often perceived as the largest importer of European startups, records a significant net outflow of startups. During the sample period, the UK "gained" 31 European startups but "lost" 189 (174 to the USA).

- Relocation leads to the majority of the startup **workforce ending up in a foreign country**.
- Startup relocation is more frequent when moving is less costly – at a **young age** and in **asset-light industries**.
- The majority of startup relocations happen in the years around the **first venture capital funding**.
- **Foreign VC investment**, particularly from the USA, is strongly associated with relocation, with the effect implying that 1 in 10 US investments leads to relocation.

Source: Weik, S., Achleitner, AK. and Braun, R. (2024). Venture capital and the international relocation of startups.

Barriers to scale-up

Evidence from stakeholder interviews

3.22. A limited sample of interviewees consistently paint a picture of a UK that excels in early-stage innovation and R&D but faces significant systemic challenges in the transition to large-scale commercialisation and manufacturing in sectors outside the dominant ones

The main scale-up challenges mentioned by the consulted stakeholders are related to finance, the cost and complexity of new technology manufacturing, securing skilled labour, and navigating an unpredictable and often unsupportive policy environment

Key theme	Challenges/barriers	Interview insights	Suggested solutions/notes
1. Finance and investment	• Difficulty accessing growth capital for manufacturing capex • UK VCs focus on software-style exits, not "brick and mortar" • Collateral requirements by business/investment banks	• "UK problem: capital access…VC finance low capital size compared to USA" • "VC funds in the UK do not want to invest in facilities…bank asks for collateral we do not have" • Innovate UK crucial but reporting onerous; SBRI easier; tax credits useful but could be better targeted	• Build a more robust capital structure • Incentivise early-stage investors (capital relief, tax incentives) • Streamline reporting for grants; refine targeting/directionality of tax credits
2. Manufacturing and infrastructure	• High production costs (energy, labour, visas) • Hard to find/repurpose facilities • Slow, complex permitting • No domestic supply chain	• "Manufacturing here is more expensive than anywhere else, e.g. visa system, energy costs" • "Germany makes facility repurposing easy; UK has no subsidies and permitting is lengthy" • All key suppliers abroad – "impossible to supply in the UK"	• Streamline permitting processes and site access • Invest in transport and energy infrastructure (rail, ports, grid connections) • Require publicly funded kit (catapults/universities) to be more accessible to firms

Source: UKIPO (2023). From public research spend to innovation: the role of registered IP.

3.23. A limited sample of interviewees consistently paint a picture of a UK that excels in early-stage innovation and R&D but faces significant systemic challenges in the transition to large-scale commercialisation and manufacturing in sectors outside the dominant ones

The main scale-up challenges mentioned by the consulted stakeholders are related to finance, the cost and complexity of new technology manufacturing, securing skilled labour, and navigating an unpredictable and often unsupportive policy environment

Key theme	Challenges/barriers	Interview insights	Suggested solutions/notes
3. Talent and workforce	• Shortage of engineers and technicians • Delays in visa/immigration systems • Lower salaries	• “Need more engineers/technicians – visa delays cost us people” • “Skills in Germany OK; UK less so” • “Electronic, mechanical, mechatronic engineers…technicians are hard to find”	• Recognise and value skilled people – streamline immigration • Improve training pathways and retention (salary competitiveness, apprenticeships)
4. Regulatory and policy environment	• Lack of long-term, clear industrial strategy • Rising employment costs (e.g. NI contributions) • Bureaucratic support bodies (e.g. catapults)	• “No policy clarity – National Insurance rising, costs unclear” • “Government shows no interest in domestic content for energy targets” • “We need sector-focused strategies, plus help navigating regulation” • R&D tax credits and IUK/ARIA grants praised; catapults could be less bureaucratic and offer more flexible IP terms	• Commit to a stable, sector-focused industrial strategy • Simplify and clarify employment-related costs for businesses • Reform catapult IP and admin processes; join up support bodies

Source: UKIPO (2023). From public research spend to innovation: the role of registered IP.

3.24. A limited sample of interviewees consistently paint a picture of a UK that excels in early-stage innovation and R&D but faces significant systemic challenges in the transition to large-scale commercialisation and manufacturing in sectors outside the dominant ones

The main scale-up challenges mentioned by the consulted stakeholders are related to finance, the cost and complexity of new technology manufacturing, securing skilled labour, and navigating an unpredictable and often unsupportive policy environment

Key theme	Challenges/barriers	Interview insights	Suggested solutions/notes
5. Ecosystem and collaboration	• Fragmented support (catapults, universities, investors not joined up) • University spinouts equity demands	• Cambridge is great for early-stage research and mentoring, but “different once you have a product and need to scale production” • Catapult model underfunded and overly bureaucratic, but positive experiences with MTC and NPL for specific support • “Universities extract too much equity from spinouts”	• Create a coordinated “one-stop” ecosystem hub for support • Align catapults, universities, and investors under shared processes • Standardise fair equity terms for spinouts
6. International context and attractiveness	• UK offers no manufacturing subsidies compared to Germany/USA • Attractive R&D base but less appealing for production	• “Firms go elsewhere to be profitable” • “Germany gives 20% capex subsidies; USA IRA and tax holidays; UK offers nothing like that” • “UK science base is world-class, so we keep R&D here but move manufacturing abroad to be profitable”	• Introduce targeted manufacturing subsidies and tax holidays • Develop domestic content frameworks (e.g. like Net Zero Industry Act) • Leverage UK science base to attract integrated R&D + manufacturing projects
7. Success Factors	• Finance, talent, market access, economic certainty are seen as critical	• “Key success = finance; ability to create tech and manufacturing through talent; access to markets; stable economic conditions. UK is weak on the first three”	• Prioritise improvements in finance access, talent pipelines, and trade certainty to reverse the UK’s relative disadvantage

Source: UKIPO (2023). From public research spend to innovation: the role of registered IP.

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SECTION 4

Technology scale-up through established firms

How significant is the role of large established firms in UK business R&D and technology scale-up?

Which technology fields and sectors dominate business innovation and R&D in the UK?

What is the level of foreign ownership among UK businesses, and what are the implications of this for technology scale-up in the UK?

Section 4 – Key findings (1/2)

KEY FINDINGS

Overall, the UK exhibits a pronounced duality in its industrial R&D and scale-up structure. On the one hand, pharmaceuticals and software development remain powerful engines of innovation and technology scale-up, boosted by strong academic research and tax incentives like the Patent Box, where large, well-resourced firms dominate IP commercialisation. On the other hand, foreign ownership has become deeply entrenched in strategic manufacturing and technology sectors, financing nearly half of all business R&D but placing long-term control and decision-making outside the UK. This is particularly evident in high-value fields such as tech hardware and electronics, where domestic players have minimal global R&D share. Meanwhile, smaller UK firms face barriers accessing patenting schemes and scaling up R&D, despite promising signs in computer programming (the top recipient of R&D tax credits) and manufacturing sub-sectors with high patent intensity.

Overall (domestic + foreign-owned) business R&D spending trends, sectoral specialisations, and the role of large firms

- **Dominance of pharmaceuticals and software development:** Pharmaceuticals (£8.7 billion) and software development (£7.6 billion) together accounted for 33% of all business R&D in the UK in 2023 (domestic + foreign-owned), followed by miscellaneous business activities (£7 billion) and motor vehicles (£4.9 billion). In 2023 total business R&D in the UK rose to £49.9 billion (+2.9% from 2022). Of this, 48% came from manufacturing (pharmaceuticals, motor vehicles, etc.), 47% from services (notably software), and 5% from other production activities.
- **Patent technology focus – software, pharma, medical tech:** From 2018 to 2023, computer technology patents represented 8.6% of UK-origin patents, followed by 7.7% in pharmaceuticals and 7.6% in medical technology.
- **Large firms dominate the UK Patent Box scheme:** Introduced in 2013, the Patent Box offers a 10% corporation tax rate on profits from patented products. Large firms dominate Patent Box use, accounting for 94% of tax relief claims. This suggests that larger manufacturers lead in commercialising patented innovations (e.g. Dyson).
- **High patent intensity in manufacturing subsectors:** UKIPO identifies 17 highly patent-intensive subsectors, with 14 in manufacturing (e.g. transport equipment, engines/turbines, special machinery). Non-metallic mineral products (4 subsectors), computers/electronics (2 subsectors), and machinery/equipment (another 2 subsectors) stand out for high patent grants per 1,000 employees. Only 2 of the 17 patent-intensive subsectors are in R&D services, illustrating that the highest patent density still resides in industrial and engineering activities.

Section 4 – Key findings (2/2)

KEY FINDINGS

- **Computer programming leads R&D tax credits:** Despite a low domestic R&D presence from large UK-owned software firms, computer programming is the top industry for R&D tax credits, followed by scientific research and development. In tax credit intensity (credits as a % of R&D expenditure), motor vehicles (20.5%) and other professional/scientific services (20.4%) rank highest, followed closely by computer programming (19%).

UK-owned business R&D trends and gaps

- **Pharmaceutical giants and R&D:** Large pharmaceutical firms perform 49% of UK-owned business R&D globally among the world's top 2,000 firms.
- **Gaps in tech hardware and electronics:** Nearly 42% of global business R&D done by the world's top 2,000 firms occurs in software, electronic/electrical hardware, and tech hardware – areas where UK-owned firms have minimal share (0.6%, 0.45%, and 0.046%, respectively). Foreign companies largely fill the gap in the UK, performing significant R&D but often retaining strategic control elsewhere.

Foreign ownership and R&D

- **High foreign share of UK business R&D:** Roughly half of UK business R&D is performed by foreign-owned companies. The UK continues to be an attractive destination for foreign direct investment (FDI), with FDI making up 48% of total business R&D spending. Domestic firms slowed their R&D investment, while foreign-owned firms increased theirs.
- **Growing trend of acquisitions:** Acquisitions of UK firms by foreign companies have accelerated since 2015 – up 4.5 times by 2023 (ONS data). For example, the proportion of foreign-controlled companies in the aerospace supply chain rose from 14% in 1990 to 41% in 2014. Many deals target high-value companies, raising concerns about local job retention, IP ownership, and strategic decision-making shifting overseas.
- **Potential consequences of foreign acquisition:** Foreign acquisitions may result in facility closures and production shifting abroad, leading to job losses, IP erosion, and negative balance-of-trade effects. Returns from foreign-owned subsidiaries count towards GDP (but not GNP), potentially overstating national income figures. Occasionally, foreign parents make UK subsidiaries global or regional HQs (e.g. GSK in Singapore for Asia), offering some local strategic autonomy.

“[**Regarding the role of big companies in the innovation system**…], much of government’s life science strategy is predicated on the role of SMEs. As drugs become more specialised, those SMEs – even if they are privately funded – are more likely to be inside the supply and value chains of the major pharma companies.”

Docherty, D., Eyton, D, Hughes, A. and Pearce, S. (2012). *Growing Value: Business-University Collaboration for the 21st Century*. A report by the Enhancing Value Task Force, CIHE and UK-IRC.

“[The large and diverse talent pool created by the Rolls-Royce University Technology Centre network…] offers a further potential employment benefit, as around a quarter of the students emerging with higher degrees and doctorates [~500] – having already been stimulated by the exacting technical ambitions of the company – ultimately secure jobs with Rolls-Royce. Others join companies within the Rolls-Royce supply chain or related organizations, and yet more remain within the academic community supporting the company’s goals.”

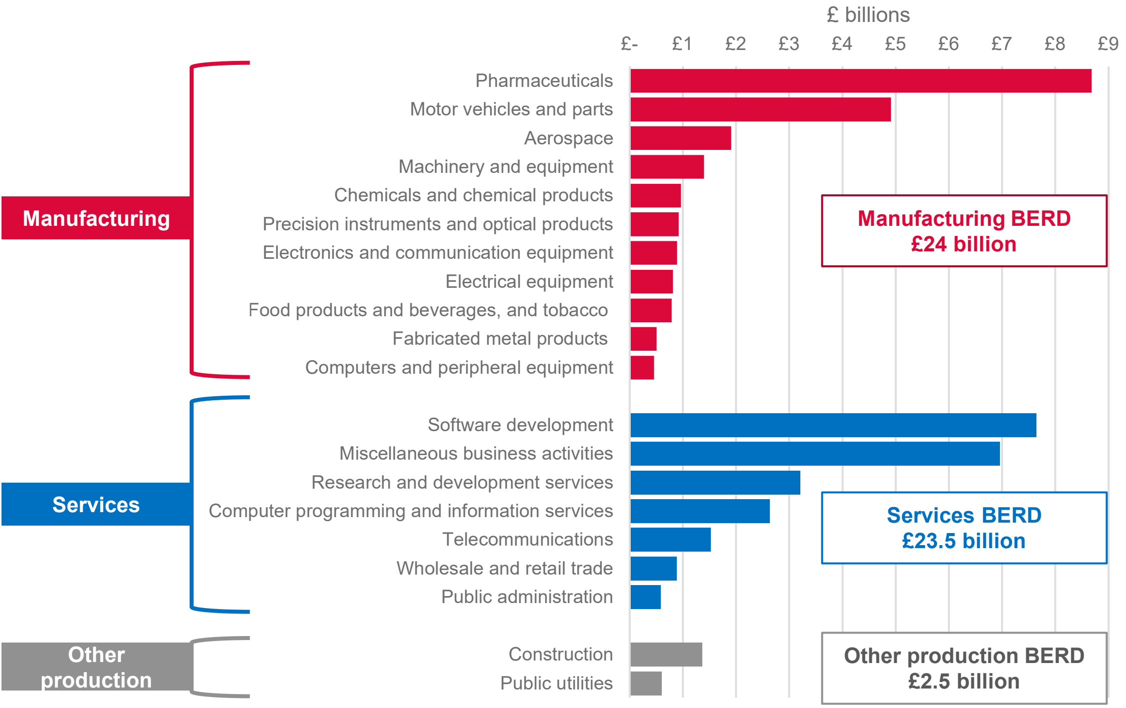
Jefferies, M. and Barnard, K. (2018). *Rolls-Royce University Technology Centres: Relationships Matter.* In *Strategic Industry-University Partnerships* (pp. 81–103). Elsevier.

“Nearly every new STEM based company set up since 1970 to have grown to employ more than a thousand people either followed this route **[soft startup model]** or spun out of a company which had done so, with customer funded R&D providing the basis for the first products sold. By enabling founders, especially those without significant funds of their own, to avoid, minimise or delay raising venture capital they were able to retain management control, achieve sustained growth and the creation of a fully rounded, profitable UK business with high levels of exports.”

Connell, David (2021). *Is the UK’s flagship industrial policy a costly failure?* University of Cambridge.

4.1. Pharmaceuticals and software development represent 33% of R&D performed in the UK by domestic and foreign-owned businesses of all sizes

R&D performed in UK businesses (BERD), top 20 product groups, 2023

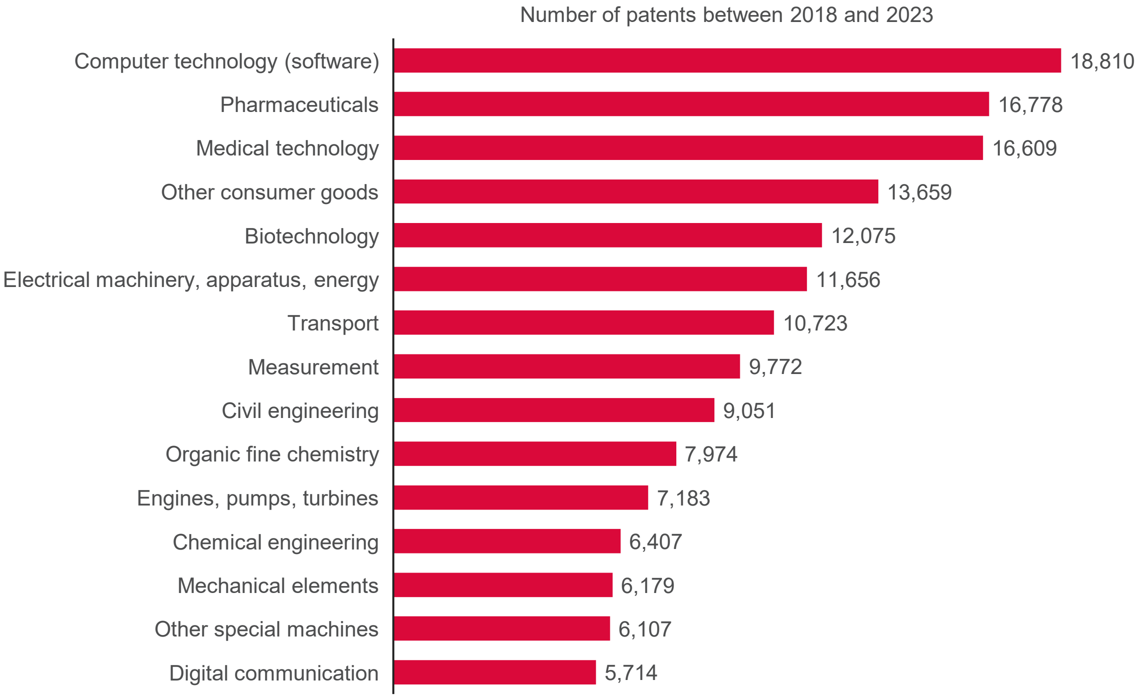


- In 2023 the R&D performed by businesses in the UK amounted to £49.9 billion, increasing by 2.9% from the previous year.
- Manufacturing products accounted for 48% of total business R&D, followed by services (47%) and other production activities (5%).
- In 2023 four products and services accounted for 56% of total UK business R&D, equivalent to £28.2 billion: pharmaceuticals (£8.7 billion), motor vehicles (£4.9 billion), software development (£7.6 billion), and miscellaneous business activities (£7 billion).

Note: *Other funds* include funds from UK private non-profit organisations and higher education establishments and international organisations.
Source: ONS (2024). Business enterprise research and development, UK: 2023.

4.2. Similarly, the top technology focus of UK-origin patents are computer technology (software), pharmaceuticals, and medical technology

UK-origin patent distribution by WIPO technology fields, 2018-2023

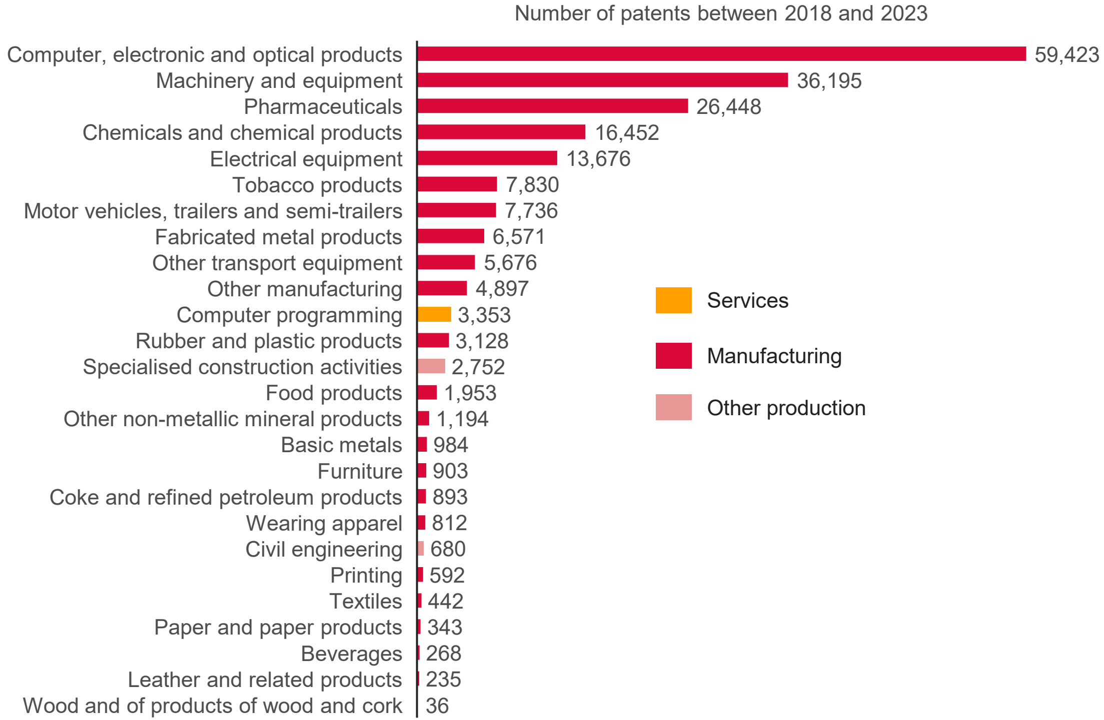


- In terms of patent technology families, as defined by the World Intellectual Property Organization (WIPO), the UK presents a technology specialisation towards computer technology, pharmaceuticals, and medical technology.
- Between 2018 and 2023, computer technology patents represented 8.6% of the total UK-origin patents, followed by 7.7% of pharmaceuticals and 7.6% of medical technology.

Source: WIPO. WIPO IP Statistics.

4.3. Meanwhile, UK-origin patents are primarily applicable to the industries of electronic devices, machinery and equipment, and pharmaceuticals

UK-origin patent distribution by industrial sector, 2018-2023



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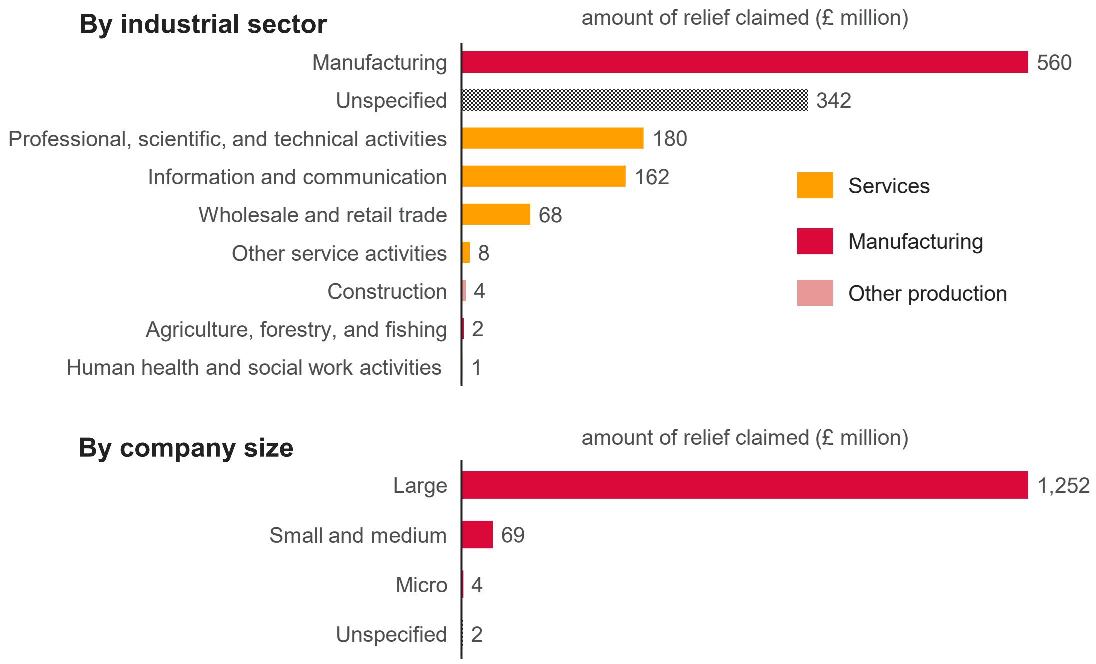
Source: EPO (2024). PATSTAT Online 2024 Autumn.

- Eurostat, in cooperation with KU Leven, developed a correspondence table between International Patent Classification (IPC) and NACE Rev. 2. Based on this table, the European Patent Office (EPO) maps patents tagged with IPC codes, mainly to manufacturing industries classified by NACE codes. [1]
- 29.2% of UK-origin patents filed between 2018 and 2023 are applicable to the manufacturing of computer, electronic, and optical products. The manufacturing of machinery and equipment, as well as pharmaceuticals, are the second- and third-largest industries for implementing UK patents.

[1] **Source**: EPO (2024). Data Catalog PATSTAT Global.
[1] **Note**: Includes applicants who are not manufacturers, such as universities, hospitals, and government organisations.

4.4. Large companies play a key role in the UK's patent filing and commercialisation of patented innovation, representing 94% of UK Patent Box tax relief value claimed

UK Patent Box tax relief claimed, tax year 2021-2022

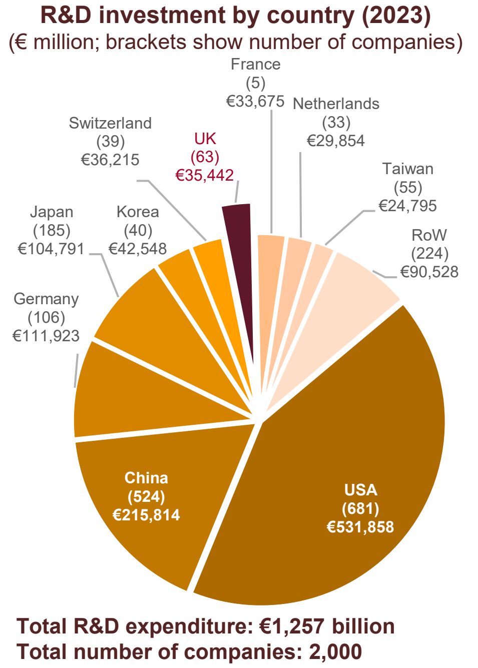


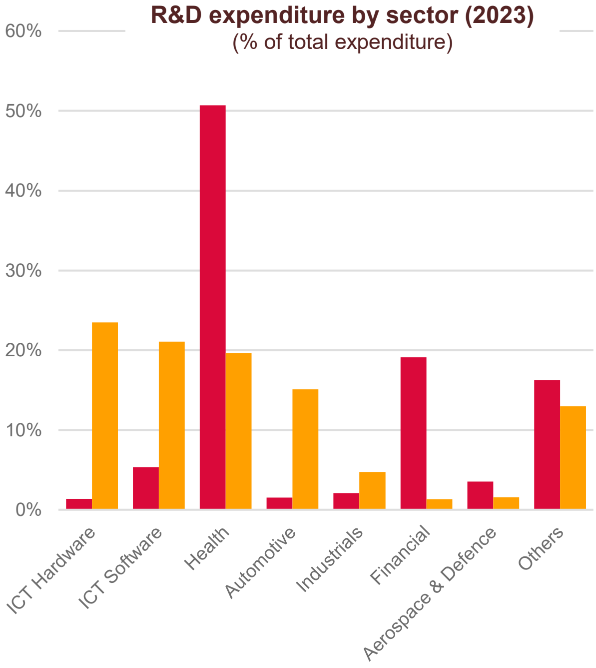
Source: HMRC (2024). Patent Box relief statistics: September 2024.

- The UK government introduced the Patent Box scheme in 2013 to encourage UK-based companies to commercialise innovation within the country. The scheme offers a lower rate of corporation tax (10%) for profits attributable to patents, including those from selling patented products.[1]
- Using the amount of Patent Box tax relief claimed by eligible UK companies as a proxy for the commercialisation of intellectual property, we see that large manufacturers in the UK dominate the commercialisation of patented innovations. Meanwhile, large companies generally outpace SMEs and micro-sized companies in patent applications.[3]
- The Patent Box relief scheme has benefited many key UK manufacturers, such as Dyson.[2]

[1] **Source**: HMRC (2023). Patent Box – Corporation Tax main rate consequential amendment.
[2] **Source**: *The Guardian* (2025). Badenoch's department wrote to Treasury after Dyson lobbying over potential tax break.
[3] **Source:** extracted from CBI Economics (2021). Prosperity Pending. Unpacking the drivers of the UK0s underperformance on the commercialisation of ideas.

4.5. Pharmaceuticals accounts for 49% of UK-owned business global R&D, while UK firms are largely absent in software, tech hardware, and electronic and electrical hardware, which represent 42% of global business R&D



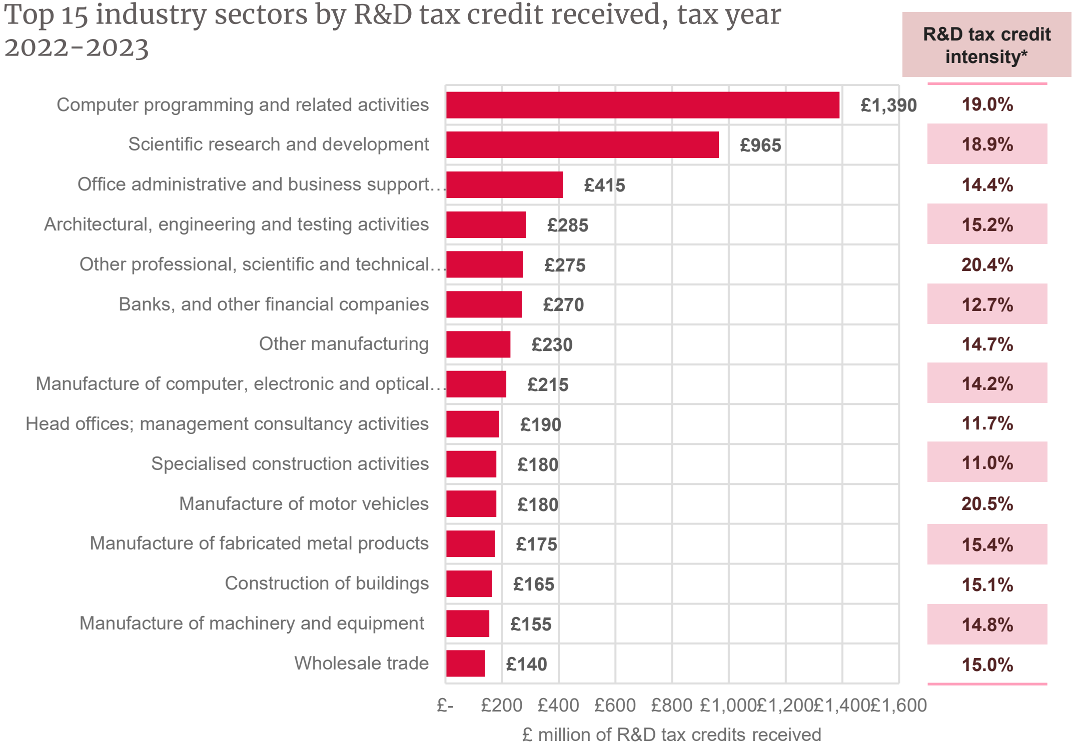


Note: RoW = rest of the world; see Appendix 2.1 for sector definition.
Source: European Commission (2024). EU Industrial R&D Investment Scoreboard; Soft Machines (2025). The world of business R&D (and the UK's place in that world).

- In 2023 the world's top 2,000 R&D investors collectively invested €1,257 billion in R&D. This accounted for over 85% of global business-funded R&D.
- The top 2,000 includes 63 UK-based firms (2.8%), and there are just 2 UK companies in the top 100 (AstraZeneca and GSK).
- Pharmaceuticals accounts for 49% of UK-owned business R&D, which is 7.5% of the world total.
- Roughly half of UK business R&D is done by overseas-owned companies.
- UK firms are largely absent in software, tech hardware, and electronic and electrical hardware, which represent 42% of all global business R&D: the UK accounts for just 0.6% of world software R&D, 0.45% in electronic and electrical hardware, and 0.046% of world R&D in tech hardware.

4.6. Despite the low participation of UK-owned businesses in global software R&D expenditure, this was the top industry by R&D tax credits received in 2022-2023

Top 15 industry sectors by R&D tax credit received, tax year 2022-2023



Note: *R&D tax credit intensity is the R&D tax credit received as a share of R&D expenditure used to claim the tax credit; data includes both SME scheme and Research and Development Expenditure Credit (RDEC) scheme claims.
Source: HMRC (2024). Research and Development Tax Credits: Supplementary tables 2024.

- The total R&D tax relief support claimed for the tax year 2022–23 was £7.5 billion (against £2.6 billion of government direct support for R&D). R&D tax credit by broad sector:
  - services – £5.1 billion
  - manufacturing – £1.7 billion
  - other production – £0.7 billion
- Computer programming and related activities received the highest R&D tax credits for the 2022–23 tax year, followed by scientific research and development.
- In terms of R&D tax credit intensity, manufacture of motor vehicles (20.5%) and other professional, scientific, and technical activities (20.4%) had the highest intensities, measured as the R&D tax credit received as a share of R&D expenditure used to claim the tax credit.

[1] **Note**: Other production includes: agriculture, forestry, fishing; mining and quarrying; electricity, gas, steam and air conditioning; water, sewerage and waste; and construction.
Source: HMRC (2024). Research and Development Tax Credits: main tables 2024.

4.7. Meanwhile, the top UK sectors by patent intensity are mostly mature manufacturing industries, such as the manufacture of other transport equipment, engines and turbines, and other special-purpose machinery

List of industrial sectors with high patent intensity, 2010-2014

SIC code	SIC description	Patent intensity measured by patents per 1,000 employees
6420	Activities of holding companies	61.26
3099	Manufacture of other transport equipment n.e.c.	55.31
2811	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	48.82
2899	Manufacture of other special-purpose machinery n.e.c.	47.44
7211	Research and experimental development on biotechnology	45.18
2311	Manufacture of flat glass	44.44
3299	Other manufacturing n.e.c.	39.23
2110	Manufacture of basic pharmaceutical products	27.97
2344	Manufacture of other technical ceramic products	25.71
2611	Manufacture of electronic components	22.33
2790	Manufacture of other electrical equipment	21.15
7219	Other research and experimental development on natural sciences and engineering	17.44
2342	Manufacture of ceramic sanitary fixtures	15.88
2352	Manufacture of lime and plaster	14.21
1395	Manufacture of non-wovens and articles made from non-wovens, except apparel	14
2051	Manufacture of explosives	13.85
2670	Manufacture of optical instruments and photographic equipment	13.83

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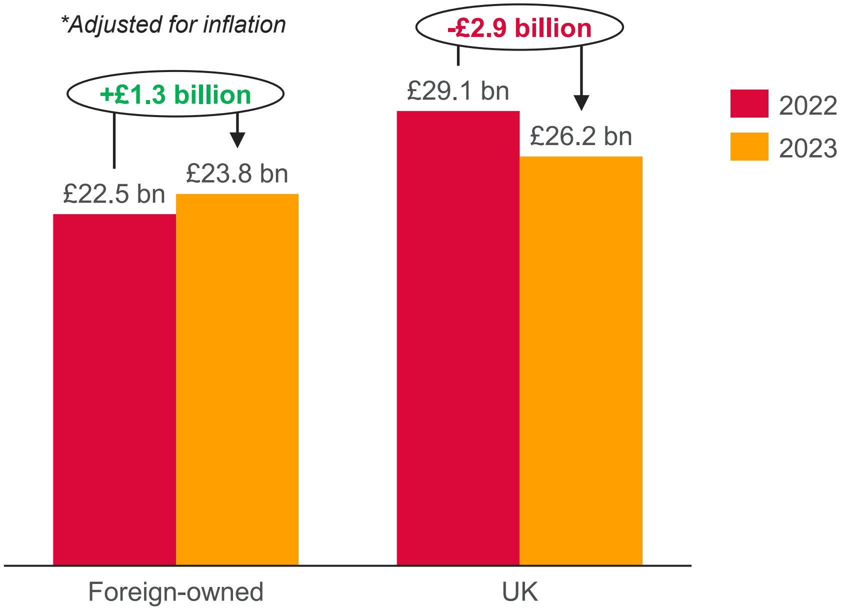
Source: UKIPO (2022). Use of Intellectual Property rights across UK industries.

- The UK Intellectual Property Office (UKIPO) identified 17 subsectors (at the 4-digit SIC code level) with high patent intensity, measured by the number of patents granted per 1,000 employees. [1]
- Of these, 14 subsectors belong to the manufacturing sector, followed by 2 from R&D services.
- The subsectors within the manufacturing of other transport equipment and machinery and equipment are among those with the highest patent intensity across UK industries.
- Among the 14 manufacturing subsectors, 4 are in the manufacturing of non-metallic mineral products, 2 belong to the manufacturing of computers and other electronic devices, and another 2 are in the manufacturing of machinery and equipment.

[1] **Source**: UKIPO (2022). Use of Intellectual Property rights across UK industries.

4.8. Roughly half of business R&D performed in the UK is done by foreign-owned companies

Total business R&D expenditure by company ownership country of origin



- Domestic companies slowed their R&D investment, while foreign-owned companies increased their R&D spending.
- Foreign direct investment (FDI), which accounts for 48% of the total business investment in R&D.
- The UK is an attractive destination for international businesses looking to innovate.

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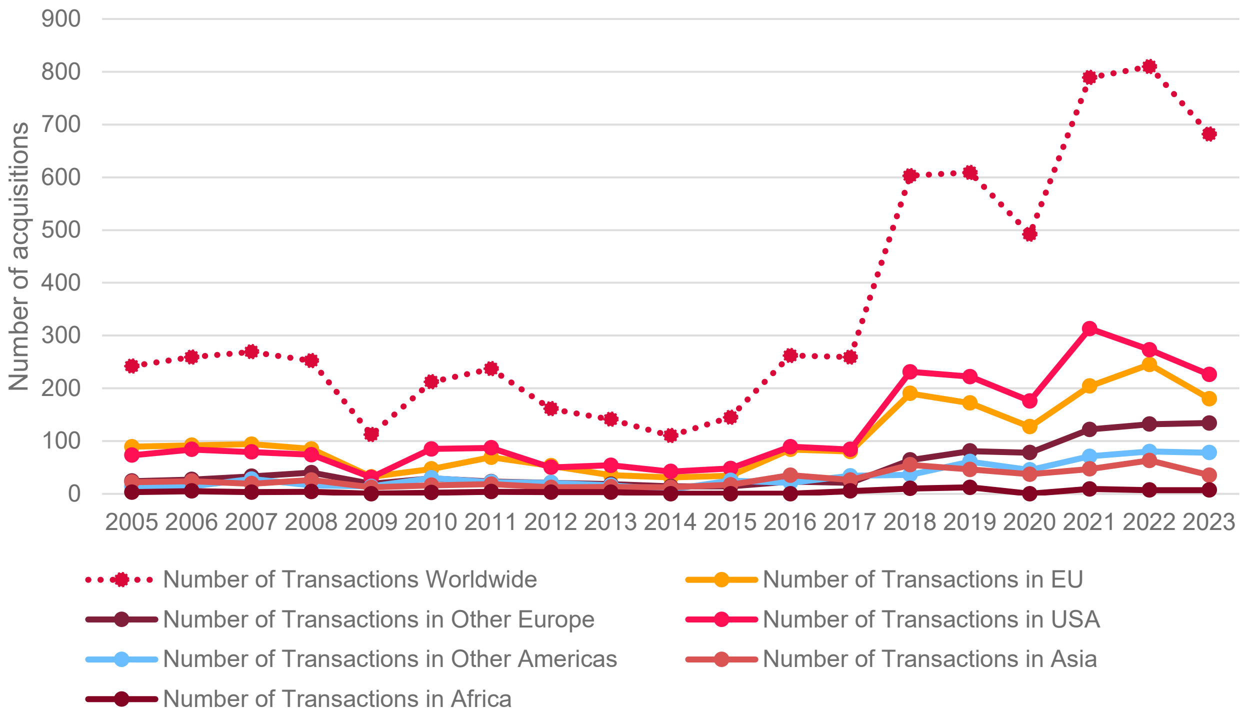
Source: NCUB (2024). UK Business R&D: A worrying decline.

4.9. The acquisition of UK firms by foreign companies has accelerated in recent years, based on data from the ONS

Acquisitions in the UK by foreign companies (2005-23)



Source: ONS (2024). Mergers and acquisitions (M&A) involving UK companies.

4.10. For example, a quarter of UK aerospace suppliers fell under foreign ownership between 1990 and 2014, with foreign acquisitions targeted at the most valuable companies

Based on a close examination of the experiences of 207 firms between 1990 and 2014, a 2015 Civitas study indicated:

- a steep rise in the proportion of foreign-controlled companies, from **14%** in 1990 (29 out of 207) to **41%** (64 out of 155) in 2014
- almost **half** (101) of the companies experiencing changes of ownership during the period, with some experiencing multiple takeover activities
- of those, more than **half** (53) ending up in foreign ownership, with 48 remaining British-owned
- **a total of 174** takeover deals associated with just **101** companies during the period studied.

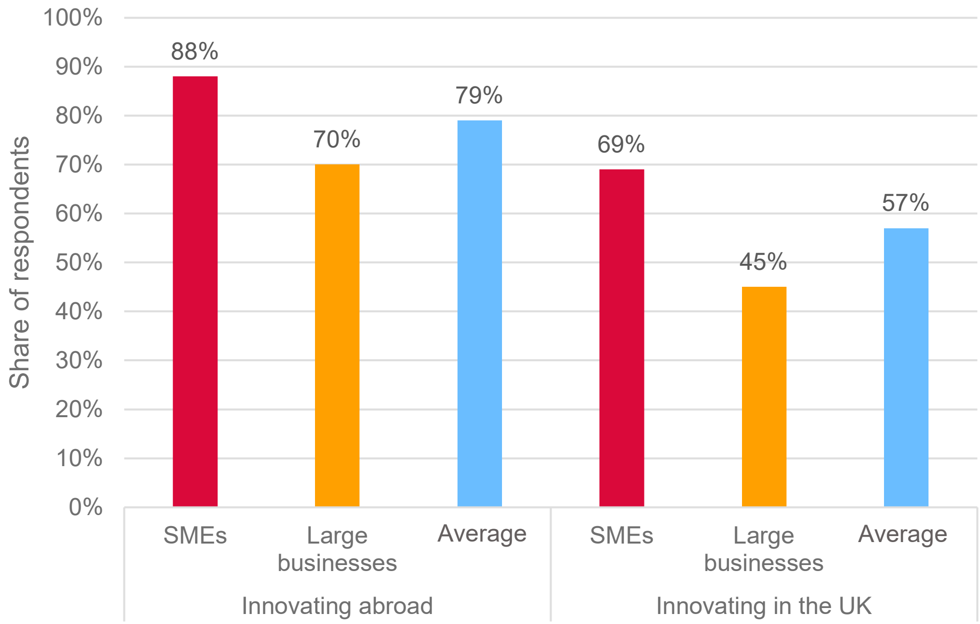
Effects of **foreign** acquisition:

1. The most damaging effect is when foreign acquisition results in the closure of a UK facility and production moves overseas. This deals multiple blows to the UK – **loss of jobs and intellectual property (IP)** and **deterioration in the balance of trade**. For example, the result of the the Longbridge motor plant in the 2005/6 Chinese acquisition was the loss of over 6,000 jobs and the transfer of the plant and equipment to China.
2. Once a firm becomes foreign-owned, its returns cease to be part of the gross national product (GNP) but remain in the gross domestic product (GDP), **flattering the presentation of national income statistics** (usually presented in GDP terms).
3. Post-acquisition strategic decisions relating to international investment, marketing, research, development, and design are almost always **made in the country of control**, usually also that of ownership.
4. Occasionally, a foreign-controlled parent will make a subsidiary of the regional or global headquarters of some part(s) of the group's business, enabling it to continue making some strategic decisions. A recent example from the pharmaceutical industry is GlaxoSmithKline's decision to make Singapore its regional headquarters for Asia.

Source: Civitas (2015). Losing Control, A study of mergers and acquisitions in the British aerospace supply chain.

4.11. Both UK SMEs and large firms report engaging in innovation abroad more than domestically

Innovation activities by company size and destination, 2024



- According to a 2024 survey of 603 UK-based R&D and innovation directors and C-suite managers, a higher proportion of SMEs in the UK engaged in innovation activities than large companies.
- Additionally, both SMEs and large firms conducted more innovation activities abroad than domestically. Overall, 79% of surveyed companies reported innovating abroad, compared to 57% within the UK.

Source: Ayming. UK Innovation Barometer 2024.

4.12. Better collaboration opportunities is the top reason for UK-based companies engaging in innovation abroad, with the USA being the leading destination

Top three destinations and reasons for offshoring R&D, 2024

Top three offshoring R&D destinations	Top three reasons for offshoring R&D
USA	Opportunities to collaborate with international partners
France	Proximity to new markets and customers
Germany	Better access to skilled R&D talent

- The USA is the top choice for offshoring R&D, selected by 32% of respondents, followed by France (17%) and Germany (15%).
- Of all the sectors, fintech and financial service companies are most likely to offshore their R&D to the USA, at 58%.
- The top three reasons for offshoring R&D include the opportunity to collaborate with international partners (38% of respondents), proximity to new markets and customers (36%), and better access to skilled R&D talent (35%).
- Notably, collaborating with partner organisations is a primary R&D resource for the manufacturing sector.[1]

Source: Ayming. UK Innovation Barometer 2025.

[1] **Source**: Ayming. UK Innovation Barometer 2023.

Annex A

Technology scale-up dimensions

A.1. Technology readiness level (TRL) (1/4)

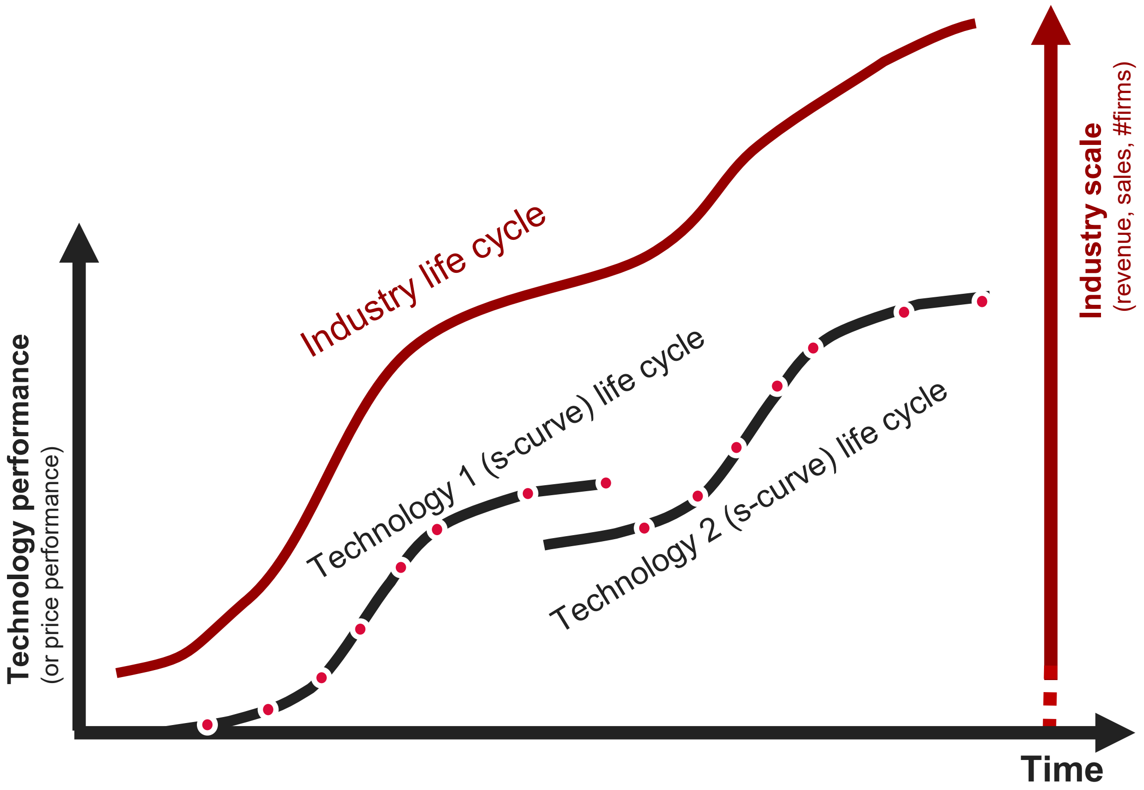
Stages

Technology readiness level	Description
1. Basic principles observed and reported	Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology’s basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions.
3. Analytical and experimental critical function proof of concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g. in an aircraft, in a vehicle, or in space).
8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development.
9. Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E).

Source: NASA

A.1. Technology readiness level (TRL) (2/4)

Scaling up over different innovation cycles: R&D programme, technology, industry



Industry life cycle: development, growth, shakeout, decline of an industry (often measured in aggregate sector sales or revenue)

Technology (s-curve) life cycle: improvement of a generic technology's performance over time

Each point on curve is effectively the performance of a particular TRL9 technology.

A.1. Technology readiness level (TRL) (3/4)

Limitations

- The linear nature of the TRL scale can be misinterpreted as implying the innovation process is linear, even though the main purpose is to enhance iterative communication/feedback between TRL stages of a highly non-linear process.
- The linear nature of the TRL scale can be misinterpreted as implying that TRL transitions correspond to even quantities of real time or levels of investment.
- In fact, development time, investment, and effort between TRLs can vary substantially from technology to technology depending on: maturity of relevant industry; maturity of associated market; complexity of system into which new technology is integrated; levels of mass production required; among other things.
- TRLs do not map one-to-one onto conventional terms such as "basic research" and "technology development", introducing scope for confusion.
- The linear nature of TRLs can be misinterpreted as implying that risk is reduced linearly with increasing TRL. For certain technologies, such as medical technologies, risk can remain very high until the final few TRLs.

Source: Dr Eoin O'Sullivan, IfM, University of Cambridge (2022).

A.1. Technology readiness level (TRL) (4/4)

Challenges

- **Challenge 1: Integration and connectivity**
  - Although the higher TRLs acknowledge that a component progresses during development from being on its own, to being part of a subsystem, to a final system, the levels offer limited insight into integration, a key challenge faced by development programmes. There is no acknowledgment of the component as a part in a connected network with dependencies, or architecture, where a change to one component would affect another.
- **Challenge 2: Interface maturity**
  - Component technologies are connected to one another in the system architecture through interfaces. The TRLs do not explicitly assess the maturity of the interfaces, despite the fact there may be new and novel ways to connect two components. Two mature technologies may interface through a novel immature interface, resulting in an overall system that is not mature.
- **Challenge 3: Influence of new components or environment**
  - Often a proven (TRL 9) technology component is chosen for use in a new system that will operate in a different environment or feature a modified architecture. This component is sometimes called a heritage technology. In these cases, assessment of the TRL can be non-obvious. It can seem unfair to discount the TRL of a proven technology, yet a pure reading of the TRL would indicate that the technology is only truly proven in the configuration and environment in which it has successfully operated.
- **Challenge 4: System readiness**
  - There is strong interest in an expansion of the (component-level) TRL assessment to a system readiness level (SRL) measure of maturity. Such a measure would allow managers to reflect on the maturity of the system as a whole, to compare it with other current projects in the portfolio or past projects, even to set system readiness requirements in the technology and product development process milestones. This measure might not just consider the TRLs of the components but also include a measure of integration or interface maturity to reflect on the system's full architecture.

Source: Olechowski, A. L. et al. (2020). Technology readiness levels: Shortcomings and improvement opportunities. *Systems Engineering*, 23: 395–408.

A.2. Manufacturing readiness level (MRL) (1/4)

Stages

- Common language for assessing manufacturing maturity of technology or product
- Complements existing technology readiness levels
- Used to assess maturity and risk of a technology's underlying manufacturing processes
- Enables rapid, affordable transition to weapon system programmes
- Designed to address manufacturing risk mitigation

MRL	Definition	Description
1	Basic manufacturing implications identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing concepts defined	Invention begins. Manufacturing science and/or concept described in application context. Identification of material and process approaches are limited to paper studies and analysis. Initial manufacturing feasibility and issues are emerging.
3	Manufacturing proof of concept developed	Conduct analytical or laboratory experiments to validate paper studies. Experimental hardware or processes have been created but are not yet integrated or representative. Materials and/or processes have been characterised for manufacturability and availability but further evaluation and demonstration is required.
4	Capability to produce the technology in a laboratory environment	Required investments, such as manufacturing technology development, identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks identified for prototype build. Manufacturing cost drivers identified. Producibility assessments of design concepts have been completed. Key design performance parameters identified. Special needs identified for tooling, facilities, material handling, and skills.

Source: US DOD (2022). Manufacturing Readiness Level (MRL) Deskbook.

A.2. Manufacturing readiness level (MRL) (2/4)

Stages

MRL	Definition	Description
5	Capability to produce prototype components in a production-relevant environment	Manufacturing strategy refined and integrated with risk management plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills, have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts initiated or ongoing. Producibility assessments of key technologies and components ongoing. Cost model based upon detailed end-to-end value stream map.
6	Capability to produce prototype (sub)system in a production-relevant environment	Initial manufacturing approach developed. Majority of manufacturing processes have been defined and characterised, but there are still significant engineering/design changes. Preliminary design of critical components completed. Producibility assessments of key technologies complete. Prototype materials, tooling, and test equipment, as well as personnel skills, have been demonstrated on subsystems/ systems in a production-relevant environment. Cost targets allocated. Producibility considerations shape system development plans. Long lead and key supply chain elements identified. Industrial capabilities assessment for Milestone B completed.
7	Capability to produce (sub)systems or components in a production-representative environment	Detailed design is underway. Material specifications are approved. Materials available to meet planned pilot-line build schedule. Manufacturing processes and procedures demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments underway. Cost models updated with detailed designs, rolled up to system level, and tracked against targets. Unit cost reduction efforts underway. Supply chain and supplier quality assurance assessed. Long lead procurement plans in place. Production tooling and test equipment design and development initiated.

Source: US DOD (2022). Manufacturing Readiness Level (MRL) Deskbook.

A.2. Manufacturing readiness level (MRL) (3/4)

Stages

MRL	Definition	Description
8	Pilot line capability demonstrated Ready to begin low-rate production	Detailed system design essentially complete and sufficiently stable to enter low-rate production. All materials are available to meet planned low-rate production schedule. Manufacturing and quality processes and procedures proven in a pilot line environment, under control and ready for low-rate production. Known producibility risks pose no significant risk for low-rate production. Engineering cost model driven by detailed design and validated. Supply chain established and stable. Industrial capabilities assessment.
9	Low-rate production demonstrated Capability in place to begin full-rate production	Major system design features are stable and proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing processes and procedures are established and controlled to three-sigma or another appropriate quality level to meet design key characteristic tolerances in a low-rate production environment. Production risk monitoring ongoing. Low-rate initial production (LRIP) cost goals met, learning curve validated. Actual cost model developed for full-rate production environment, with impact of continuous improvement.
10	Full-rate production demonstrated and lean production practices in place	This is the highest level of production readiness. Engineering/design changes are few and generally limited to quality and cost improvements. System, components, or items are in rate production and meet all engineering, performance, quality, and reliability requirements. All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six sigma or another appropriate quality level. Full rate production unit cost meets goal, and funding is sufficient for production at required rates. Lean practices well established and continuous process improvements ongoing.

Source: US DOD (2022). Manufacturing Readiness Level (MRL) Deskbook.

A.2. Manufacturing readiness level (MRL) (4/4)

MRL “threads” (risk elements analysed at each level)

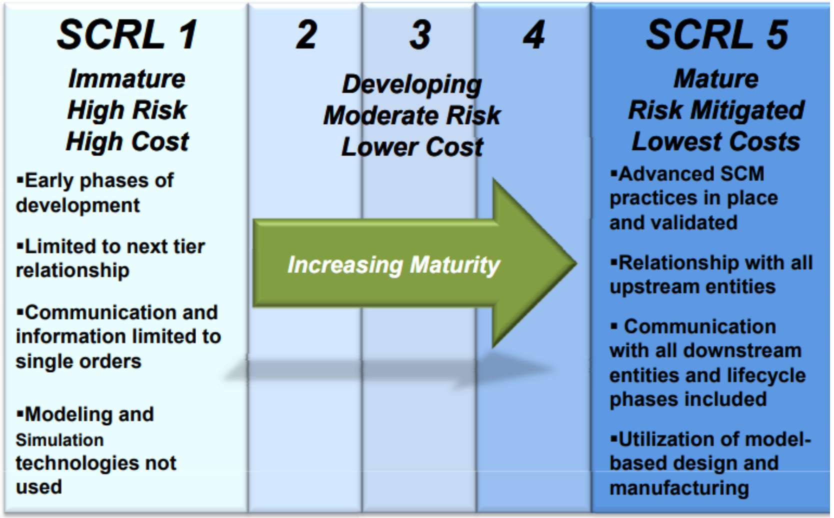
- **Industrial base and manufacturing technology:** analysis of capabilities of national technology and industrial base to support design, development, production, operation, uninterrupted maintenance support of system, and eventual disposal.
- **Design:** analysis of degree to which identified, evolving, or system design will meet user requirements and to which the design is new and unproven.
- **Materials:** analysis of risks associated with materials (including basic/raw materials, components, semi-finished, parts, and sub-assemblies).
- **Cost and funding:** analysis of the risk that system development and deployment will not meet the R&D (mission) agency cost and funding goals.
- **Process capability and control:** analysis of the risk that manufacturing processes may not be able to reflect design intent (repeatability and affordability) of key characteristics.
- **Quality management:** analysis of risk and management efforts to control quality and foster continuous quality improvement.
- **Manufacturing workforce:** assessment of required skills and availability in required numbers of personnel to support the manufacturing effort.
- **Facilities:** analysis of the capabilities and capacity (prime, subcontractor, supplier, vendor, and maintenance repair) that are key risks in manufacturing.
- **Manufacturing management:** analysis of orchestration of all elements needed to translate the design into an integrated and fielded system.

Source: US DOD (2022). Manufacturing Readiness Level (MRL) Deskbook.

A.3. Supply chain readiness level (SCRL) (1/2)

SCRLs and “threads” (risk elements analysed at each level)

The term “supply chain readiness levels” (SCRL) was initially proposed by Brian Tucker from the University of Alabama, Huntsville. It has 5 levels of maturity designed for human space operations and also involved risk and cost, analysed using 15 threads.



Inventory	Strategic raw material, WIP and FG placement in SC
Strategic Sourcing	Sourcing decisions benefit enterprise, optimum number of SKUs & supp.
Visibility	Ability to see varying levels of the SC
Suppler /Cust Relationships	Working relationships at varying levels of the SC, Improvement focus
Price Adaptability	Impact of variation in the price of commodities
Collaboration	Flow of information up and down the supply chain
Lifecycle Awareness	SC visibility and awareness of the current lifecycle phase
Modeling & Simulation	Apply modeling and simulation to improve SC
Performance Measurement	Metrics used to measure and improve supply chain
Risk Management	Including obsolescence, sole-sourcing, counterfeit parts
Criticality Focus	Focus level on critical parts, path and suppliers
Sustainability	Long term viability of the industrial base
Manufacturing Readiness	Monitoring manufacturing readiness of the SC
Technology Readiness	Monitoring technology readiness of the SC
Sub-Tier Management	All levels of SC adhere to SCRL standards

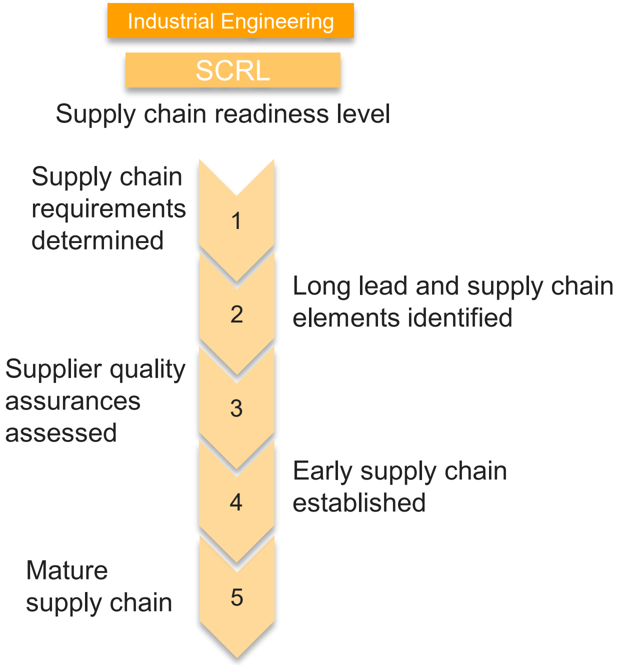
Total of 15 Threads

Source: Tucker, B. (2010). SCRL-Model for Human Space Flight Operations Enterprise Supply Chain.

A.3. Supply chain readiness level (SCRL) (2/2)

SCRLs and “threads” (risk elements analysed at each level)

The MRL scale from the US Department of Defense “Manufacturing Readiness Level (MRL) Deskbook” contains various levels specifically related to supply chain readiness. These have been extracted and employed in the analysis framework introduced in Slide 14.



Source: US DOD (2022). Manufacturing Readiness Level (MRL) Deskbook.

A.4. Business and market readiness level (B&MRL) (1/2)

Stages

The KTH Innovation Readiness Level is a framework developed by KTH Innovation at the KTH Royal Institute of Technology in Stockholm, Sweden. It is designed to help researchers, entrepreneurs, and innovators assess and develop their ideas into viable products or services. The framework is modelled after the technology readiness level (TRL) but is tailored to the innovation process, encompassing a broader spectrum of readiness, including market and business aspects.

Level	Description
1	○ Vague and unspecific description of the potential business idea or business concept. ○ Little insight into the market and its potential/size – hypothesising about possible applications. ○ Little knowledge or insight into competition and alternative solutions.
2	○ Describes the proposed business concept in some structured form. ○ One or several markets or applications are identified and described on overall level, for example user numbers, TAM-total available, or addressable market (everyone you wish to reach). ○ Some competitors and/or alternatives are identified and listed.
3	○ There is a draft of the business model in a canvas format (business model canvas/lean canvas) but typically without the revenue/cost parts and details. ○ The market description is more highly resolved, with more specific market applications and segments being identified. Target applications identified. ○ The market potential and market size are quantified with TAM and SAM segmented/served available/addressable market (everyone you have decided/can reach). ○ A more complete competitor overview with direct/indirect competitors and alternatives.
4	○ There is a full business model in canvas format, including details of possible revenue/costs. ○ First economic projections with numbers to show the market potential and economic viability (bottom-up calculations based on projections/guesstimates on volumes, prices, etc.). ○ Assessed feasible share of market based on, for example, barriers to entry, including competition. ○ Made a competitive analysis on your position and uniqueness/differentiation versus them.

Source: KTH (2024). Business Readiness Level.

A.4. Business and market readiness level (B&MRL) (2/2)

Stages

Level	Description
5	○ The business model (at least parts of it) is tested against customers to verify hypotheses. ○ The business model is updated and refined to new version based on customer feedback. ○ There is a first version of a more detailed revenue model, including pricing hypotheses (What revenue streams are there, from what, when, how, and what prices are possible?) ○ The competitive position and differentiation are verified by market feedback.
6	○ A complete business model, including pricing, is tested versus customers by test sales or similar. ○ The revenue model, including pricing, is updated and refined based on customer feedback. ○ First more complete projections on revenue/costs (profit and loss projections or similar) with more details and well-grounded assumptions/data (e.g. 1–3 years horizon).
7	○ There is product/market fit, meaning you can demonstrate significant customer interest and use of products and sales where customers show clear payment willingness. ○ Attractive revenue versus cost projections (being validated by sales and data), implying a sustainable/attractive business could be built. ○ Preparations for scaling business with suppliers, sales channels, etc. (including agreements).
8	○ Business model is final and business is scaling with growing and recurring revenue. ○ The business scales by growing in new markets, new geographies, new segments, etc. ○ There is a working business, which is profitable and sustainable over time.
9	○ Sales and other metrics show the business model holds and is profitable, for example customer acquisition is not costing too much. ○ The business model shows it can scale (potentially globally). Sales channels and supply chain are fully in place. ○ Business model is set but is continuously fine-tuned to explore more revenue options.

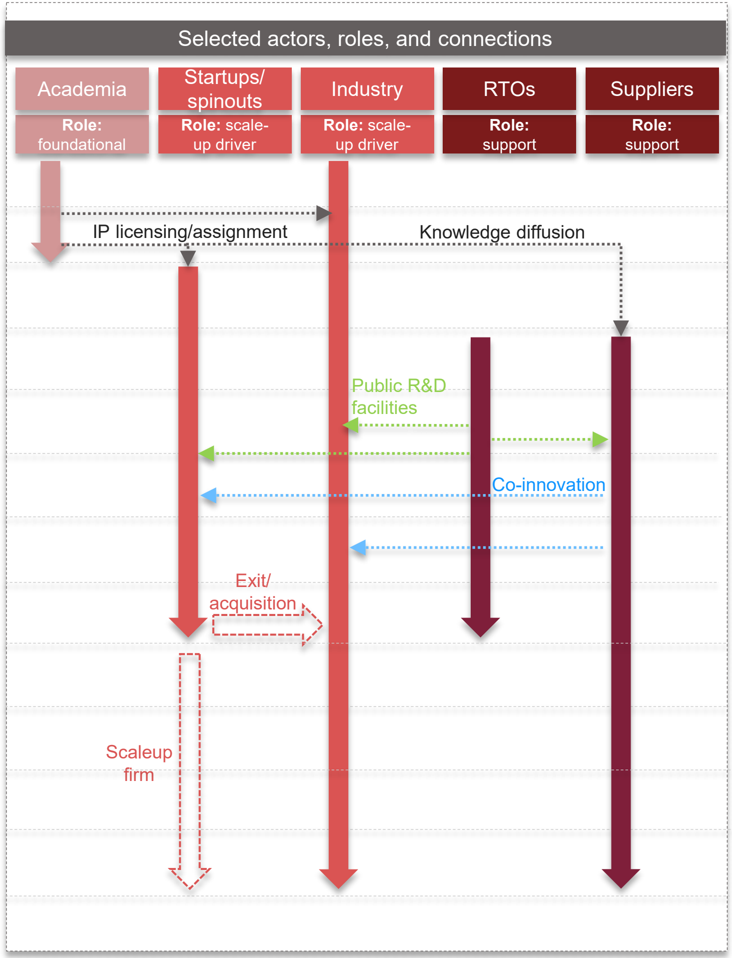
Source: KTH (2024). Business Readiness Level.

A.5. Actors involved in driving technology scale-up (1/3)

Translating an innovation into a market involves multiple stages and actors:

Simplified linear innovation model stages and actors involved	
1) New knowledge: Universities conduct research and make discoveries.	
2) Disclosure: Academics disclose inventions to the university technology transfer office (TTO).	
3) Evaluation: TTOs evaluate commercial potential and patentability.	
4) IP protection: TTOs file for IP protection.	
5.1) Transfer to spinouts/startups: license/assign IP to startups. Develop business plans, secure funding, and form the company. OR	**5.2) Transfer to established firms**: license/assign IP to corporations. Negotiate terms, integrate into R&D.
6.1) Scale-up by spinouts/startups: develop prototypes, validate the market, refine the product, obtain approvals, launch, and scale the business. OR	**6.2) Scale-up by established firms:** integrate IP, allocate resources, develop products, obtain approvals, launch, and scale using existing infrastructure.
OR **7.1) Spinouts/startups maturity/exit:** startup acquired by a corporation.	

- ❑ Scientific uncertainty
- ❑ Scientific risk
- ❑ Technical risk
- ❑ Engineering uncertainty
- ❑ Manufacturing uncertainty
- ❑ Market Risk & Uncertainty
- ❑ Exogenous Risk & Uncertainty



Source: Author's creation based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

A.5. Actors involved in driving technology scale-up (2/3)

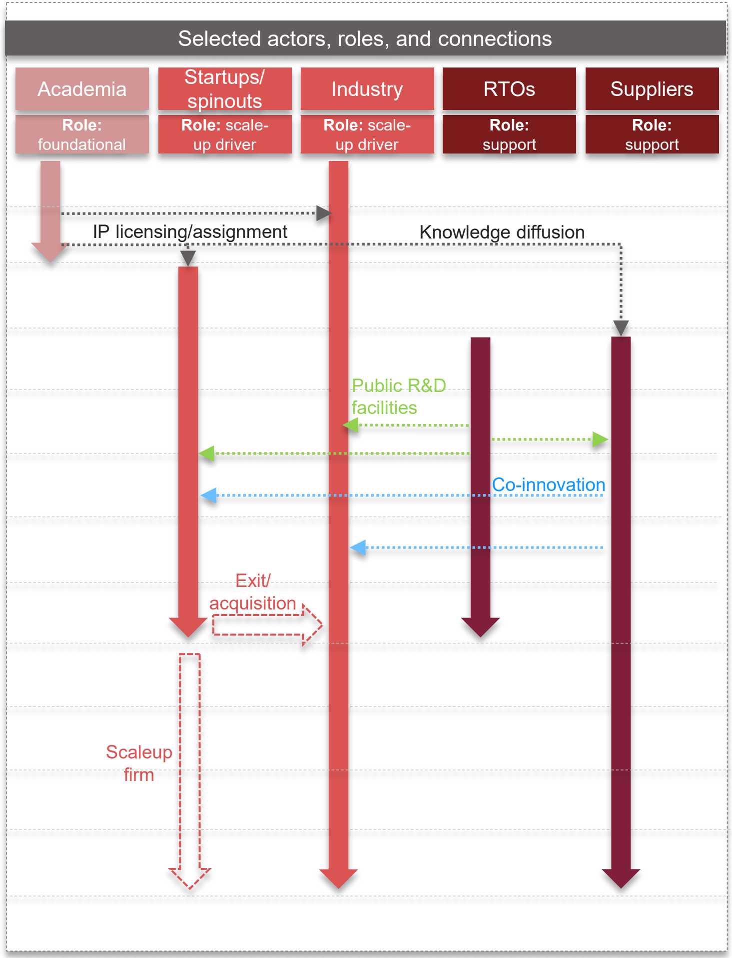
Beyond universities, startups, and corporations, other actors in the innovation play important support roles during the scale-up process, namely research and technology organisations (RTOs) and suppliers:

Research and technology organisations (RTOs)
RTOs play a pivotal role in bridging the gap between basic research and market-ready products by providing essential public infrastructure and support mechanisms that help scale up and de-risk new technologies, facilitating their transition into commercially viable products and processes.

Key roles:

- **Infrastructure provision:**
  - **Facilities and equipment:** RTOs offer access to advanced laboratories, testing facilities, and specialised equipment that might be too expensive for individual startups or small businesses.
  - **Pilot plants and demonstration sites:** They provide pilot plants and demonstration sites where new technologies can be scaled up from lab-scale to industrial-scale production in a controlled and supportive environment.
- **Technical expertise:**
  - **Specialised knowledge:** RTOs possess a wealth of technical expertise across various fields, which can be crucial for refining and optimising new technologies.
  - **Consultancy services:** They offer consultancy services to help businesses troubleshoot technical challenges and improve their products and processes.

- ❑ Scientific uncertainty
- ❑ Scientific risk
- ❑ Technical risk
- ❑ Engineering uncertainty
- ❑ Manufacturing uncertainty
- ❑ Market risk and Uncertainty
- ❑ Exogenous risk and uncertainty



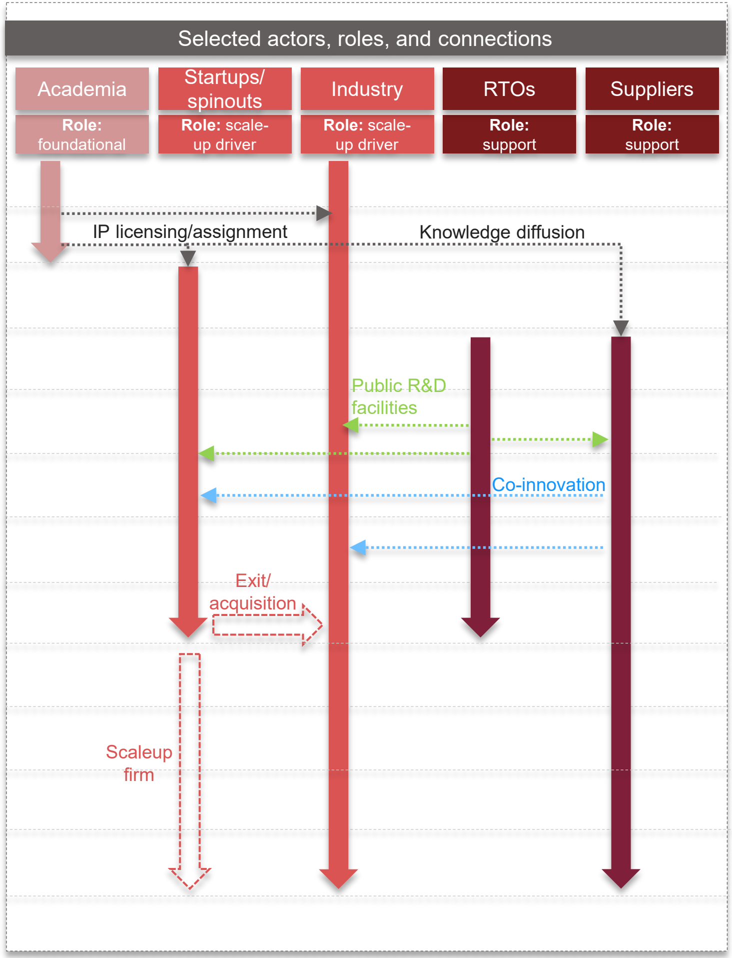
Source: Author's creation based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

A.5. Actors involved in driving technology scale-up (3/3)

Beyond universities, startups, and corporations, other actors in the innovation play important support roles during the scale-up process, namely research and technology organisations (RTOs) and suppliers:

Supplier firms
Supplier firms play a crucial role in the innovation ecosystem by collaborating with established original equipment manufacturers (OEMs) and startups to scale up and de-risk new technologies.
Key roles: ➢ **Technical expertise and innovation:** ○ **Specialised knowledge:** Supplier firms often possess deep expertise in specific components, materials, and manufacturing processes that can be leveraged to improve the design and functionality of new technologies. ○ **Co-development:** They engage in co-development activities with OEMs and startups, contributing to the innovation process by suggesting improvements, providing technical solutions, and sharing their R&D capabilities. ➢ **Prototyping and testing:** ○ **Prototype manufacturing:** Supplier firms help in the rapid prototyping of components and subsystems, enabling the testing and iteration of new designs quickly. ○ **Testing and validation:** They offer testing facilities and services to validate the performance, reliability, and safety of new technologies, ensuring they meet industry standards and customer expectations. ➢ **Manufacturing and production support:** ○ **Scale-up manufacturing:** Supplier firms have the capability to scale up production from prototype to full-scale manufacturing, providing the necessary infrastructure and expertise.

- ❑ Scientific uncertainty
- ❑ Scientific risk
- ❑ Technical risk
- ❑ Engineering uncertainty
- ❑ Manufacturing uncertainty
- ❑ Market risk and uncertainty
- ❑ Exogenous risk and uncertainty



Source: Author's creation based on O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches.

A.6. Scale-up actors and their contextual challenges (1/2)

Although startups and established firms are the main drivers of technology scale-up, they operate within very different contexts, with startups characterised by agility and resource constraints, while established firms benefit from extensive resources and market reach but face bureaucratic challenges.

Characteristics	Startup firms	Established firms
Financial resources	Limited funding, often reliant on grants, angel investors, venture capital	Substantial funding, access to internal cash flow, corporate venture funds
Human resources	Small, highly focused teams, often lacking in specialised expertise	Large, diverse workforce with access to specialised experts and departments
R&D infrastructure	Limited R&D facilities, may use shared or rented lab space	Extensive in-house R&D facilities and laboratories
Market access	Limited market reach, reliant on partnerships and initial customer acquisition efforts	Established market presence, strong distribution channels, and customer base
Brand recognition	Low brand recognition, need to build reputation from scratch	High brand recognition, established credibility, and trust
Speed and agility	High agility, can pivot quickly and adapt to changes	Slower to change, bureaucratic processes can delay decision-making
Risk tolerance	Higher risk tolerance, more willing to take significant risks	Lower risk tolerance, focus on sustaining existing business alongside innovation
Innovation culture	Strong innovation culture, driven by necessity to disrupt markets	Varies, often need to foster intrapreneurship to encourage innovation
Decision-making process	Fast decision-making, often centralised among a few key individuals	Slower, more hierarchical decision-making involving multiple stakeholders
Access to networks and ecosystems	Limited access to innovation ecosystems and accelerators	Extensive networks, strong relationships with suppliers, partners, and academia
Support services	Limited access to support services because of funding constraints, often rely on external public scale-up infrastructure	Comprehensive in-house support services (legal, marketing, HR, etc.), complemented by public scale-up infrastructure access
Regulatory knowledge	Limited regulatory knowledge, need external guidance	Extensive regulatory expertise and dedicated compliance departments
Scalability of operations	Limited scalability, need to build infrastructure as they grow	High scalability, existing infrastructure can support large-scale operations
Technology transfer	Often need to negotiate access to external IP and technology	Strong capabilities for internal technology transfer and integration

Source: Authors' creation, based on Hölttä-Otto, K. et al. (2013). Innovation differences between new venture startups and incumbent firms. International conference on engineering design, ICED13, 19–22 August 2013, Sungkyunkwan University, Seoul, Korea.

A.6. Scale-up actors and their contextual challenges (2/2)

Although startups and established firms are the main drivers of technology scale-up, they operate within very different contexts, with startups characterised by agility and resource constraints, while established firms benefit from extensive resources and market reach but face bureaucratic challenges.

Characteristic	Startup firms	Established firms
Production facilities	Limited or outsourced manufacturing facilities	Extensive in-house manufacturing facilities and capabilities
Scale-up capabilities	Challenging to scale quickly, often need external partners	High scalability with existing large-scale production infrastructure
Manufacturing expertise	Limited in-house expertise, often rely on external consultants or partners	Extensive in-house expertise across various manufacturing domains
Quality control systems	Basic or developing quality control systems	Advanced, well-established quality control and assurance systems
Supply chain management	Developing supply chain networks, often rely on third-party logistics	Robust and integrated supply chain management with established supplier relationships
Technology integration	More flexible and open to adopting new manufacturing technologies	Ability to integrate advanced manufacturing technologies, though can be slower because of scale and legacy systems
Customisation and flexibility	High flexibility and ability to customise products rapidly	More rigid processes but can leverage extensive resources for customisation when needed
Innovation in manufacturing	High potential for innovative manufacturing approaches as a result of fewer legacy constraints	Continuous improvement and innovation through dedicated R&D in manufacturing
Time to market	Fast prototyping and iteration, but slower to full-scale production	Slower initial prototyping but faster scale-up and market entry once production starts
Workforce skills	Smaller, versatile teams with broad skill sets	Large, specialised workforce with deep expertise in specific areas
Partnerships and collaborations	Reliant on forming partnerships for manufacturing capabilities	Strong existing partnerships with suppliers and co-manufacturers

Source: Authors' creation, based on Hölttä-Otto, K. et al. (2013). Innovation differences between new venture startups and incumbent firms. International conference on engineering design, ICED13, 19–22 August 2013, Sungkyunkwan University, Seoul, Korea.

Annex B

Lessons from international experience

B.1. Scope of scale-up infrastructure reviewed

The term *scale-up infrastructure* or its related proxies is less commonly mentioned as a standalone concept in many countries. However, in our international review, we distinguish scale-up infrastructure from research infrastructure, highlighting its specific role and purpose within the innovation ecosystem.

Research infrastructure
open to research communities

Facilities providing resources and services aimed at the research communities' needs to conduct research and foster innovation, including:

- associated human resources
- major equipment or sets of instruments
- knowledge-related facilities
- other infrastructure of a unique nature, essential to achieve excellence in research,

where relevant, to be used beyond research, for example for education or public services.

Scale-up Infrastructure
open to industrial players (including SMEs)

Hardware for process/production scaling up

- novel R&D/engineering tools (e.g. software tool such as modelling, stimulation, and digital twin)
- demonstration facility and equipment (e.g. pilot lines, system demonstration testbed).

Services for business scaling up

- market analysis
- company organisation adaptation
- supply chain and key partner development
- skill development.

B.2. Awareness of scale-up infrastructure importance in countries reviewed

Country	Awareness level	Details
Denmark		In Denmark, scale-up infrastructure is commonly referred to as “innovation infrastructure” or “test, demonstration, and development facilities”. Their scope and characteristics are well defined and widely acknowledged in policy documents, grey literature, and government-backed initiatives such as the RESEARCH2025 Catalogue. Example: the policy paper of The Technological Knowledge Bridge – Now and in the Future by the GTS institutes (government-backed RTO network).
Germany		Scale-up infrastructure is encompassed in a broader scope of research infrastructure and not distinguished as a separate concept. The terms used to refer to scale-up infrastructure include “industrial research facilities” or “application-oriented research infrastructure”.
Japan		In Japan, scale-up infrastructure is implicitly encompassed in a broader definition of research infrastructure and not distinguished as a separate concept. The most relevant terms include “research infrastructure”, “research facilities”, and “research equipment”.
Sweden		The concept of scale-up infrastructure is explicitly emphasised in Sweden’s national STI policy papers, with a clearly defined scope and criteria. It is commonly referred to as “innovation infrastructure” or “test and demonstration environment”. Example: Research and innovation bill 2021-2024 provides a clear definition of “test and demonstration environment”.
Switzerland		The most relevant concept to scale-up infrastructure is Centres of Technological Excellence, which is to “foster knowledge and technology transfer by creating synergies between the private sector and the research activities pursued within the Swiss higher education sector”. Meanwhile, the Swiss Innovation Parks also encompass elements of scale-up infrastructure.

B.3. Efforts on mapping and roadmapping exercises

Country	Effort level	Details
Denmark	 	**Mapping**: The national authorities and the GTS institutes carry out dedicated mapping efforts to enhance industrial users' access to public scale-up infrastructure. A new mapping exercise is scheduled in 2025. **Roadmapping**: There is no roadmapping exercise aimed at scale-up infrastructure in Denmark. However, the Ministry of Higher Education and Science carried out two roadmapping exercises in 2015 and 2020 that focused on research infrastructure, which included certain elements of scale-up infrastructure.
Germany	 	**Mapping**: Although mapping and inventory activities are absent at a national level, many scale-up infrastructure providers maintain inventories of their hardware and services to inform potential external users. **Roadmapping**: Scale-up investment strategies are developed in a bottom-up and decentralised way by individual RTOs, universities, and other providers. They make investment decisions on scale-up infrastructure through internal strategic processes, while remaining aligned with the political objectives set by federal, regional governments, and the EU.
Japan	 	**Mapping**: Comprehensive mapping and inventory activities are conducted by the public sector and research institute associations to increase the accessibility of R&I facilities available in public research institutes across Japan. **Roadmapping**: The national government conducts regular foresight studies (for both technology and dedicated, large-scale infrastructure) every 5 years to inform high-level strategies, white papers, and specific programmes.
Sweden	 	**Mapping**: Mapping and inventory activities in Sweden are carried out by government agencies and regional authorities and through specific programmes. These efforts aim to enhance the accessibility and visibility of scale-up infrastructure for industrial users. **Roadmapping**: Vinnova and RISE have conducted several roadmapping exercises in recent years, focusing on identifying industrial needs and addressing challenges related to the development of scale-up infrastructure in Sweden. But a national roadmapping exercise based on facts and robust analyses is needed.
Switzerland	 	**Mapping**: Limited mapping exercises for scale-up infrastructure conducted by the public sector. **Roadmapping**: Limited roadmapping activities conducted by the public sector to capture the future demands on scale-up infrastructure.

B.4. Denmark

***Why**: scale-up challenges and opportunities addressed*

Across the EU: The lack of scale-up and technology diffusion are identified as the main barriers to industrial transformation in the EU, with innovations not translated into new markets and growth opportunities systematically, because of **insufficient infrastructure investment.** *(European Commission (2019). Technology Infrastructures – Commission Staff Working Document)*

Denmark: A long-term investment in large infrastructure for material synthesis, including pilot plants and cleanroom facilities for micro and nanofabrication, will likewise help to maintain a Danish position of strength within innovative products based on new materials. (*Danish Agency for Science and Higher Education (2018). Research2025*)

***What**: key instruments and programmes*

GreenLabs-DK: Green Labs DK was established in 2009 to supplement the Energy Technology Development and Demonstration Programme (EUDP). The purpose of Green Labs DK is to close a gap in the Danish chain of innovation to establish facilities for demonstrating and testing climate technologies at large scale and under realistic conditions. The programme is strategically oriented towards the promotion of pre-commercial development, demonstration, and scaling of (new) energy technologies, linked to the Danish strategy 2030.

Business LightHouse Programme: A national programme launched in 2021 from a framework agreement between Denmark's Business Promotion Board and the Minister of Business on the startup of business lighthouses, which aim to boost development and employment, leveraging the potential of the individual parts of the country within selected positions of strength. These lighthouses participate in establishing testing and demonstration facilities accessible to knowledge institutions and businesses to evaluate future solutions and technology.

Innobooster programme: A programme funded by the Innovation Fund Denmark that provides support to knowledge-based development projects in small and medium-sized Danish enterprises (SMEs) and entrepreneurial companies, and can provide support for companies to access scale-up infrastructure. Projects receiving support may be focusing on market maturation or testing of a prototype or service in real user situations with potential customers or end users.

***How**: funding models*

Mixed funding schemes from the national, regional, and EU authorities.

Public funding is channelled to support various stages of scale-up infrastructure development. This includes investment in the creation and upgrade of scale-up infrastructure (CapEx) and operational funding (OpEx) to enhance accessibility of industrial users to the infrastructure.

Public funding from the **national and regional governments** in Denmark must adhere to **EU State Aid** rules, which limit the share of funding allocated to testing and demonstration facilities.

EU funding programmes are important sources for the investment in scale-up infrastructure.

Danish RTOs adapted their business models to increase revenue from **the private sector**, helping to partially cover their operational costs. Additionally, **private foundations** in Denmark play a crucial role in supporting RTOs and scale-up infrastructure.

***Where**: technology/sector focus*

- Construction and facilities; energy; digital technologies; climate and environment; materials technology; production technology; service innovation; health and food; and transportation.

B.5. Germany

***Why**: scale-up challenges and opportunities addressed*

Across the EU: The lack of scale-up and technology diffusion is identified as the main barrier to industrial transformation in the EU, with innovations not translated into new markets and growth opportunities systematically, because of **insufficient infrastructure investment.** *(European Commission (2019). Technology Infrastructures – Commission Staff Working Document)*

Germany: Germany has a broad research landscape with strong basic and applied research. But Germany is **lagging behind** in the forward-looking area of cutting-edge technologies and digitisation. *(BMBF (2023). Future strategy for research and innovation)*

***What**: key instruments and programmes*

Open Innovation Test Beds (OITB): Open innovation test beds (OITBs) are clusters of laboratories, test infrastructure, and innovation service providers working together under a single entry point (SEP) to facilitate innovators, in particular SMEs, access to services for the development, TRL progress, and commercial implementation of innovative products and technologies. The aim of OITBs is to make nanotechnologies and advanced materials available to companies and users to move from validation in a laboratory (TRL 4) to prototypes in industrial environments (TRL 7). Open access in this context means any interested company from Europe and beyond has access to the facilities, skills, and services of the test beds.

Joint Industrial Research: A Europe-wide unique, open-topic, and pre-competitive funding programme of the Federal Ministry for Economic Affairs and Climate Protection that offers small and medium-sized enterprises (SMEs) easy access to practice-oriented research.

INNO-KOM: Fund pre-competitive R&I projects by non-profit industrial research institutions, the results of which are made available to SMEs. Provide financial support for their research and development projects in preliminary research (VF) and market-oriented development (MF).

APECS pilot in semiconductor operated by Fraunhofer: Create links between RTOs, manufacturers, material and equipment suppliers, design houses, startups, SMEs and foundries; grant SMEs and startups long-term autonomous access to the services, portfolio, and infrastructure set up for them.

***How**: funding models*

Generally, innovation funding streams from the **public sector** are divided into institutional and project funding, supported by the national and/or regional level.

- Both Institutional and project fundings for scale-up infrastructure providers cover both their CapEx (e.g. INNO-KOM) and OpEx (e.g. Joint Industrial Research).
- The institutional funding is split by 90% from federal and 10% from regional levels. While for the investment in new institutes or areas, the respective regional entities co-fund up to the half of the cost.

The German R&I system has one of the highest shares of **private spending** on R&I worldwide. The use of scale-up infrastructure by both large and small enterprises constitutes a significant portion of this spending. In 2022, enterprises spent €27.6 billion on commissioned R&I projects, with medium-sized enterprises playing a key role in outsourcing R&I work to external parties

EU funding, such as the European Structural and Investment Funds, plays a crucial role in supporting scale-up infrastructure investment at the federal, regional, and institutional levels.

***Where**: technology/sector focus*

- **Nationwide** lighthouse projects delivering federal funding specific to scale-up infrastructure aimed at specific fields, including maritime energy, battery cell, microelectronics and hydrogen, AI, quantum, automotive, manufacturing.
- **Regional** authorities in Germany define technology and sector priorities tailored to their strengths. For instance, the region of North Rhine-Westphalia (NRW) has launched an application-oriented research programme targeting six key areas, including materials and production, mobility and logistics, ecology and circular economy, energy and construction, medicine and life sciences, media and services, and key future technology.

B.6. Japan

***Why**: scale-up challenges and opportunities addressed*

Establishment of Domestic Infrastructure and Promotion of Innovation by Startups *(Cabinet Office (2024). Integrated Innovation Strategy 2024)*:

- To secure an advantage in new markets, we will promote the early creation of use cases and markets by industry, academia, and government as an exit strategy for R&D. We will also strengthen the development and use of test beds and the accumulation of data and know-how as bases and hub functions for this purpose.
- Startups are also important players in innovation. We will use the bases and hub functions of industry, academia, and government to nurture startups and support innovation generation. In particular, we will work to create a strong ecosystem that supports the long-term growth of startups in the field of advanced science and technology, which often requires larger and longer-term funding than other fields.

***What**: key instruments and programmes*

Open innovation laboratories: Since fiscal year 2016, AIST (National Institute of Advanced Industrial Science and Technology) has been developing ”open innovation laboratories”, or OILs, which are industry–academia–government collaborative research hubs to be set up on university campuses and other locations, as part of the "Open Innovation Arena Initiative" promoted by the Ministry of Economy, Trade and Industry. By establishing OIL, we will combine basic research at universities and other institutions with AIST's basic research and applied technology development, and promote the "bridge" between technology and industry.

Local public technology research centres (*Kosetsushi*): Kosetsushi can be interpreted as a form of an innovation intermediary. Currently, there is at least one manufacturing Kosetsushi in each prefecture, which play three key roles in regional innovation systems:

- They diffuse technological knowledge through various routes, such as testing, use of analytical equipment, technical consultation, joint research, and seminars for engineer education.
- They conduct their own research, patent inventions, and license patents, mainly to local SMEs.
- They act as a catalyst for local SMEs to develop innovative networks to external sources of knowledge.

Industry-led technical research consortia: National funding agencies support to establish industry-led technical research consortia focusing on various sectors. Next-generation floating offshore wind power technology development project is an example funded by NEDO.

***How**: funding models*

Large-scale investment in R&I equipment (CapEx) is usually funded by **the national government**; the operational costs (OpEx) of large-scale R&I infrastructure are partially supported by the national government through a combination of basic and competitive funding.

Around 88% of the budget of regional public research institutes came from **regional authorities**, and the remaining revenue is from services, including testing, R&D, commissioned research, IP revenue from the national government, and other sources like local SMEs. The income generated by equipment loan was less than 1%.

The **private sector** typically commissions research tasks to public research institutes and universities; but it is uncommon for the private sector to directly fund hardware there with the aim of gaining access to it. On the other hand, the national funding agencies support the establishment of **industry-led** technical research consortia focusing on various sectors. Each industrial consortium owns relevant scale-up hardware, including labs, instruments, and devices.

***Where**: technology/sector focus*

- AI, biotech, quantum, and materials are highlighted in the current **6th STI Basic Plan**, in which the effective use of the infrastructure in the public and private sectors to accelerate the development of these technologies is an implicit target.
- In the **regional level**, manufacturing-based centres often establish branches tailored to the specific technological strengths of each region, such as ceramics, electronics, or chemicals. Owing to their direct engagement with local clients via technical consultations, researchers at these centres gain deep insights into the industrial needs.

B.7. Sweden

***Why**: scale-up challenges and opportunities addressed*

Across the EU: The lack of scale-up and technology diffusion are identified as the main barriers to industrial transformation in the EU, with innovations not translated into new markets and growth opportunities systematically, because of **insufficient infrastructure investment.** *(European Commission (2019). Technology Infrastructures – Commission Staff Working Document)*

Sweden: The availability of relevant test and demonstration environments in all parts of the country constitutes a central function in a well-functioning and internationally competitive innovation system. (*Government Offices (2020). Research bill 2021-2024*)

***What**: key instruments and programmes*

Impact Innovation: Impact Innovation is Sweden's innovation venture for the 2030s. A strategic and long-term mobilisation, where we solve global societal challenges together and increase the pace of transition to a sustainable society. All programmes will be shaped around a goal, a mission, which a group of stakeholders will develop together. To ensure the programmes are successful, the constellations of stakeholders must be wide. Large and small innovative companies from industry and organisations from the public sector and civil society, research institutes, and academic institutions are probably required. New organisations may need to join over time, and others may need to leave after a while.

Innovation and IP vouchers: To strengthen the innovativeness and competitiveness of SMEs. Vouchers can be applied for activities related to scale-up infrastructure: access to labs, test beds, test and demo facilities, production facilities, and similar infrastructure, which are needed to verify and validate various production and development-critical properties. This includes computational capacity and major IT infrastructure.

Vehicle Strategic Research and Innovation (FFI): The collaboration has led to in-depth collaboration and consensus, a strengthened competitiveness and relevance in the automotive industry, as well as increased competence, knowledge, and scientific quality in vehicle strategic research and innovation. We have financed over 900 projects where over 500 organisations have participated and contributed. New knowledge has been built up within the industry, universities, and research institutes.

***How**: funding models*

Public funding schemes for scale-up infrastructure in Sweden are predominantly **project-based**, with Vinnova being the primary national funding agency.

Public base funding is allocated to RISE, which is tasked with developing and enhancing cutting-edge environments for testing, demonstration, and pilot production. RISE is also responsible for ensuring that end-users, particularly industrial stakeholders, are actively involved in funding, development, and operations.

Funding from **industrial associations –** such as those representing the automotive and quantum industries – and **the EU** plays a crucial role in supporting both the capital expenditure (CapEx) and operational expenditure (OpEx) of scale-up infrastructure.

***Where**: technology/sector focus*

- Additive manufacturing; AI; automated vehicles; batteries; concrete and cement; biotech; green technology; digital infrastructure (cybersecurity, data science, digitalisation); and design.

B.8. Switzerland

***Why**: scale-up challenges and opportunities addressed*

Switzerland: Interviews highlight that awareness of scale-up infrastructure among industry is a potential challenge and something that the public sector could potentially assist with. In short, because of the strongly market-driven ethos, it is important that firms are aware of the scale-up infrastructure that is available to them, which may not always be the case. There is a need for more incentives to get the private sector and private partners to work on projects requiring the services of TIs.

Another challenge faced by the infrastructure providers was that the federal support can cover operational costs, but in cases of rapid technological advancements that may require significant changes or large and costly improvements in the physical infrastructure to accommodate this, it becomes challenging to finance. An infrastructure provider indicated that CAPEX-like funding opportunities to keep the infrastructure beyond state-of-the-art is missing. *(European Commission (2024). Policy Landscape supporting Technology Infrastructures in Europe)*

***What**: key instruments and programmes*

Swiss Innovation Park: Established in 2016, the Swiss Innovation Park is a public–private partnership of “national importance”, supported by the federal government, the cantons, the scientific community, and the private sector. It comprises 16 sites across 6 parks, offering a combined 300,000 square metres of laboratories, cleanrooms, offices, event spaces, and coworking facilities.

Innosuisse: Innosuisse supports projects from all fields of innovation and interdisciplinary projects. Innosuisse financially supports science-based innovation projects conducted by industrial partners and private and public institutions together with a research partner in all subject areas to develop new types of product, service, or process together. This offering is aimed at implementation partners: SMEs, large companies, startups, administrative bodies, non-profit organisations, other private and public institutions; research partners: scientific researchers.

***How**: funding models*

Federal government: limited funds focusing on the operating expenditure of the facilities and infrastructure, which are of “national importance”.

Regional government (canton): The regional funding is often operated on an ad hoc or on-demand basis, lacking a broader, cross-sectoral perspective.

Private sector: Project-based and private-led funding stream provides most of the funds for scale-up infrastructure.

***Where**: technology/sector focus*

- **Regional governments** focus on areas aligned with their own industrial ecosystem and strengths, while **federal funding** is limited to infrastructure deemed of “national importance”:
    - The focuses of the Swiss Innovation Park include health and life sciences; computer and computational science; energy, natural resources and environment; mobility and transportation; and manufacturing and materials.
    - The focus of the canton of Zurich: cleantech, finance, ICT, and life sciences.
    - The focus of the canton of Bern: mechanical, precision, watchmaking and medical technology industries.

B.9. Example 1: advanced materials (1/2)

The EU

Challenges for creating an inclusive ecosystem for advanced materials	
Fragmentation of the research and innovation (R&I) ecosystem	• In the absence of a joint and coordinated strategy, public resources on R&I in advanced materials are fragmented and do not sufficiently strengthen EU competitiveness and innovation capacity.
Private investments are not commensurate with increasing needs	• The EU industrial R&I investments on advanced materials are not even half of those in the USA (€19.8 billion investment in 2020 compared to €50.3 billion), followed closely by South Korea and Japan (with €19.6 billion and €14.0 billion, respectively), with lower investments by Chinese industry (€7.7 billion).
A lack of progress in circularity and material efficiency	• The EU circular material use rate is currently stagnating below 12%, and R&I on materials is still not focusing enough on circularity, for example because of a lack of in-depth knowledge of material flows.
Long innovation processes and an insufficient level of digitalisation	• The digitalisation of research and development has the potential to accelerate the discovery of innovative materials, and Europe could benefit from better exploitation of digital tools in this area.
Disconnect between innovative research and uptake in industrial applications and processes	• The gap between groundbreaking research and industrial application leads to limited collaboration and strategic alignment, hindering the integration of advanced materials into industries.
A lack of testing and experimentation facilities	• Technology infrastructure with facilities for experimentation, prototyping, testing, and piloting help to bring products to market faster. Tech industries, notably startups and small and medium enterprises (SMEs), often cannot afford in-house infrastructure and therefore need better access to such facilities to be able to validate and optimise new and essential technologies before commercialisation.
Need for harmonised standards	• To promote market uptake and ease the regulatory process, it is equally important to ensure the harmonisation of standards for materials characterisation, materials performance, and safety and sustainability assessment methodologies.

Source: European Commission (2024). Advanced Materials for Industrial Leadership

B.9. Example 1: advanced materials (2/2)

The EU

Materials processing and production scale-up challenges
Low resource use, energy-efficiency and decarbonisation of materials processing
Industry-ready processes and technologies for establishing renewable material sourcing, manufacturing, and/or recycling value chains in Europe
Innovative materials processing technologies and solutions
Increased product customisation, guarantee, and labelling
Support product traceability and life cycle management

Cross cutting R&D challenges	
Process optimisation	• Higher speed; flexibility • Resource savings and efficiency (energy, water, consumables, etc.) • Separation process optimisation • Match process characteristics and materials properties, including by online (continuous) process monitoring
Decarbonisation	• Energy savings; electrification; renewable sources • Hydrogen economy and hydrogen production with low carbon footprint • CO2 capture, storage, conversion, use • Catalysts (including bio-based)
Mass Customisation	• Consumer/customer integration • Highly flexible, reconfigurable engineering, production, and logistics processes • Supply chain management
Zero defect production	• New, more accurate and intelligent sensing systems to collect relevant data • Simulation at laboratory scale of potential failure mechanisms, accelerated tests, feedback to the process • Process and product tracking along the complete value chain
Circular economy	• Rapid and cost-effective assembly, de-assembling, repairing, de- and re-manufacturing recycling of materials, multilayer or hybrid, including re- and de-functionalisation • Waste valorisation processes with an emphasis on complex materials mixtures (e.g. construction, electronic) • Eco-design along the value chain • Resilient use of trusted secondary materials (including tracing from sourcing)
Multi-materials processing	• Design of the material and related properties • Production, joining/assembling, and de-assembling
New materials processing	• New, adapted processing and production technologies and solutions, and their optimisation for new materials

Source: AMI (2022). Materials 2030 roadmap. [Initiative involving European Commission and MANUFUTURE, EUMAT, SUSCHEM, EMIRI ETP]

B.10. Example 2: quantum technologies (1/2)

The USA

Challenges for creating an ecosystem quantum technologies	
Low private investment	• Investment dilemma suppliers/developers: reluctance on both sides because of low sales volumes, unclear developed technology, and unclear market demand
Limitation in research and development facilities	• Existing fabrication processes aren't consistent across different facilities • Foundries for active PICs don't exist • Lack of federal support and funding for scaling and infrastructure (e.g. on ultra-high vacuum chambers/pump systems) • Expensive access to testbeds – need to facilitate broader access via government support
Lack of supply chain integration Disconnect between vendors and developers/integrators	• More extensive interaction between integrators and technology suppliers needed, including the latter in the process as early as possible • Language/knowledge barrier between vendors and developers/integrators
Lack of domestic supply of components	• Supply chain needs, such as greater domestic supply of components and higher quality materials • Lag in delivery times – delays and issues if international political challenges • Electronic tracking, offshoring, and IP offshoring has created a challenge to address the need for domestic fabrication of FPGAs and laser and laser controls (especially tunable lasers) • Lack of long-term planning with encouragement of local supplier development or specialised service providers
Shortage of specialised technical and engineering talent	• Need for quantum workforce with cross-cutting expertise (programming, engineering, quantum, optics)
Need for harmonised standards	• Need for set approaches and configurations and consensus around standards to enable higher production volumes and bring down costs • Getting all system integrators on the same page and willing to share their specs because of a lack of pull from integrators for consolidation of needs • Lack of standard configuration or set of components and materials

Source: International Center for Innovation Strategy and Policy (2023). Quantum technology manufacturing roadmap (QTMR).

B.10. Example 2: quantum technologies (2/2)

The USA

Materials processing and production scale-up challenges
Introduction of new materials into a process: new materials require new processes that can lower yields when introduced. Lack of current volumes is keeping vendors from making investments in these areas. Consolidating spec information across applications in a common source would help guide the material research process.
Specifications, handling, and preservation: need for basic research to understand precise requirement. Need to improve handling and preservation processes. Improvement needs in packaging technology.
Intellectual property concerns: business model challenges to prevent others from reproducing systems. Example: crystal growth tools. Companies view modelling methods as proprietary (system and device modelling).

Cross-cutting R&D challenges	
Tool customisation	• Customised tools typically give integrators more flexibility in the materials and configurations they employ, but the low purchase volume leads to high prices and long lead times
Scale manufacturing (mass production)	• Need for integrators to prioritise most important aspects for industry progress (trade-offs) • Need for greater knowledge sharing of configurations and specifications for both fabrication tools and cryogenic systems
System integration and use	• Better design tools are also needed, especially in areas such as on-chip integration – some of these tools exist, but they are not widely available for purchase and use by system developers • Less complex software that can be used by technicians and open source software
Quick prototyping	• Chip fabrication: some progress is being made to provide the needed fabrication capabilities, but these may not be low-cost and may not be able to provide the quick turnaround times for iteration on prototypes (ion and neutral atoms)
Testing and quality control	• Lack of standards around testing, diversity in protocols for different types of qubit, and lack of adequate testing workforce • There will probably always be areas of deeper expertise required to integrate components
System and device modelling	• Lack of shared data as a short- and long-term challenge to creating better tools for system and device modelling • Achieving more accurate modelling will require government investment in research or a significant industry player to address the challenge

Source: International Center for Innovation Strategy and Policy (2023). Quantum technology manufacturing roadmap (QTMR).

B.11. Example 3: quantum technologies (1/5)

The EU

(Challenges) Recommendations/actions for creating an ecosystem quantum technologies	
(Limitation in or lack of) need for research and development facilities	• There is [therefore] a great need for technology transfer and focused development of superconductor technology in larger manufacturing facilities; moving from university cleanrooms to reliable manufacturing facilities for large-scale QPUs will be quite costly, but is important to achieve technological sovereignty and secure critical supply chains • Build up European infrastructure, know-how, and a supply line for the fabrication of qubit chips using advanced semiconductor manufacturing techniques • This will require EU investment in DC/RF characterisation capabilities under cryogenic conditions • Establishing foundries able to manufacture the required technology, including integrated photonics, cryogenic, and superconducting electronics • Foster access to quantum simulators by industry end-users and startups (for Q simulation) • Built testbeds for quantum internet technology to develop, demonstrate, and showcase the technology • Creation and use of pilot lines for improved access of companies and researchers to quantum platforms that are useful to develop quantum sensors • Improve access to, and streamlining of, fabrication and packaging facilities; consider leveraging existing pilot line investments and workflow • Accelerate the development of critical European enabling technologies for quantum computing, quantum simulation, and quantum communications
Need for domestic supply of components	• Reduce lead times and costs by reducing the dependency on materials and components from non-European sources • Supply chains need to be implemented to support new installations, as well as maintaining existing ones • Simultaneously, we must protect and strengthen our own control points in the supply chain and foster situations based on reciprocity; monitoring the supply chains over time will be necessary to safeguard our position and alleviate potential bottlenecks • Foster the creation and growth of critical component manufacturers within the EU, while striving towards security of supply for non-EU components

Source: European Commission (2024). Strategic Research and Industry Agenda European Quantum Flagship, EU.

B.11. Example 3: quantum technologies (2/5)

The EU

(Challenges) Recommendations for creating an ecosystem quantum technologies	
Need for vendors/suppliers/developers and integrators	• Enlarge Europe's commercial quantum tech ecosystem by bringing on board chip foundries and other hardware providers, public or industrial, as well as the software industry, existing companies, and a new cohort of startups • Expand and strengthen the supply chain and the development of key enabling technologies (for quantum simulations) • Establish a reliable, efficient supply chain, including materials, fabrication facilities, enabling technologies, quantum devices, and sub-systems for quantum sensors
Need for specialised technical and engineering talent	• Developing a suitable workforce and training programmes will be paramount to building interdisciplinary and cross-domain skills between HPC and QCS across science, engineering, systems, software development and programming, algorithms and applications • An additional challenge is the training of active researchers and users, as well as contributions to education within university curricula in computer science/engineering and computational sciences, to support early quantum literacy at least at the level of MSc and PhD • A well-functioning value chain in quantum technologies requires well-trained personnel in other stakeholder groups such as project and product and innovation managers, CXOs, business analysts, marketing and sales, and human resources
Need for interdisciplinary communication	• Leverage interdisciplinary expertise and join forces with other fields, such as the signal processing community, to advance the limits of sensors sensitivity and resolution and to implement the best control protocols, statistical techniques (e.g. Bayesian), and machine learning algorithms for sensor-specific signal processing and algorithms

Source: European Commission (2024). Strategic Research and Industry Agenda European Quantum Flagship, EU.

B.11. Example 3: quantum technologies (3/5)

The EU

(Challenges) Recommendations for creating an ecosystem quantum technologies	
Need for connection between vendors and developers/integrators	• Foster close collaboration between hardware and software providers; foster the development of co-design hardware and software tailored to specific applications • Support co-design/co-development of quantum simulators between industrial end-users and quantum manufacturers (hardware and software) to accelerate work towards the demonstration of “quantum advantage” for industry-relevant purposes using quantum simulators (for Q simulation) • Build a bridge between industry and research on quantum simulation to translate the problems of industry into the language of simulation paradigms • Establish a well-defined framework to support increased collaboration and knowledge transfer in the European HPC-QCS ecosystem between related Digital Europe and Horizon Europe Programmes, particularly to synergise the developer and user communities across Member States
Lack of investment	• There is a lack of a business environment in which providers and integrators have the incentives to develop and implement commercially available QKD services; to achieve this, future business opportunities, investment, and sponsorship should be developed • The EU, with several of its Member States, like other governments across the globe, has started to set up funding mechanisms to support local quantum companies, but European private investors have not yet followed suit • The EU is home to roughly 25% of global startups and SMEs in the quantum technology sector, on par with the USA, but EU companies attract only 5% of private investments in the sector, 10 times less than similar companies in the USA • Venture capital funding of startups has plunged by more than 50% in the past 12 months, and this scarcity of capital could lead to an “extinction event” for the EU’s quantum scale-ups, where companies collectively holding hundreds of patents on innovative intellectual property (IP) are unable to close funding rounds and are abandoned or sold to foreign competitors at discounted prices

Source: European Commission (2024). Strategic Research and Industry Agenda European Quantum Flagship, EU.

B.11. Example 3: quantum technologies (4/5)

The EU

Materials processing and production scale-up challenges
Develop industry-standard fabrication facilities that can assemble and integrate large high-quality quantum processors Develop a proof of concept for large-scale, optimised, and efficient cryogenic systems
Promote the growth of an expanded industry for demanding components and technologies used in QC, with the aim of enhancing standardisation and reducing production costs
Establish fabrication processes and demonstrate performance from quantum devices fabricated in industrial-grade facilities, comparable to state-of-the-art from specialised (e.g.) university clean rooms

Cross-cutting R&D challenges	
Characterisation techniques	• Scalable characterisation techniques and system-engineering bottlenecks should be identified at this level • And reliable ways to quantify material properties (e.g. microwave/optical losses, flux noise, two-level-system density) and how they translate to quantum circuit devices and gate performance also needed
Development of key enabling technologies	• Device integration, electronics packaging, and signal delivery are other important engineering tasks • Packaging and miniaturisation of quantum systems, together with the supporting systems, which requires significant developments in the enabling technologies, including cryogenics, photonics, and semiconductor technologies • Development of key enabling technologies, such as photonic integrated chips (PIC), low-noise and RF electronics, miniaturised lasers, traps, atom chips, vacuum systems, cryogenic systems, photonic modulators, and frequency converters and atomic vapor cells
Prototyping and testing	• Fabrication facilities to prototype and test solutions towards error-corrected universal QC: higher gate fidelities, more qubits • The challenge is to develop a network of testing and characterisation labs with globally unique equipment and competencies, that will be the infrastructure offering traceable testing and validation services (quantum sensing)
Cryogenic systems	• Investigate the scale-up of cryogenic systems, to overcome technological bottlenecks, such as heat load demands and power consumption • Develop reliable cryogenic setups that will greatly improve the lifetime of atoms in tweezer

Source: European Commission (2024). Strategic Research and Industry Agenda European Quantum Flagship, EU.

B.11. Example 3: quantum technologies (5/5)

The EU

Cross-cutting R&D challenges	
System integration	• Integrate quantum and classical hardware (through cryogenic electronics and/or efficient wiring and control) to develop quantum processors that can be scaled to very large numbers (eventually millions) of qubits • In parallel, explore better integrating optical, photonic, and electronic components with the ion trap in a way that supports scalability (in the number of ions and in repeatable industrial production) – devise integrated cryo-compatible solutions for signal multiplexing • (Neutral-atom qubits) The interfacing with classical electronic hardware is more complex than other technologies • (Colour-centre qubits) A focus on device fabrication and integration (integrated optics and qubit controls) will be essential for future scalability • Achieve integration of quantum simulators with HPC systems
Standardisation and certification	• Support standardisation of qubit control for future implementations • Provide general methods for the certification and benchmarking of quantum simulators • Establish standards and metrics defined by standardisation developing organisations (SDOs) for quantum communications • The level of maturity of current standards for QKD is low, and to ensure a secure and reliable service, these standards need to evolve • Establish standardisation, calibration, and traceability (in a metrological sense) for new sensor technologies and prototypes of compact electrical quantum standards with enlarged application ranges
Software development	• Develop the needed programming interfaces (in the form of APIs and languages) to support easy access from developers
IP and regulations concerns	• Collaborations in quantum technology often involve sharing sensitive data and information, and differences in data protection regulations, privacy laws, and cybersecurity standards between the EU and the USA can raise concerns about data privacy, security breaches, and compliance with regulatory frameworks • Policies, regulations, and ethical considerations related to quantum technology can change over time, potentially influencing ongoing collaborations – staying updated with regulatory developments and adapting collaboration strategies is important

Source: European Commission (2024). Strategic Research and Industry Agenda European Quantum Flagship, EU.

B.12. Example 4: synthetic biology (1/2)

Australia

Challenges for creating an ecosystem synthetic biology	
Lack of industries in the sector	• This early level of industry activity is promising but Australia will need to accelerate the translation and commercialisation of synthetic biology applications if it is to build a critical mass of synthetic biology industry activity • Limited large-scale therapeutics manufacturing capabilities; during consultations, stakeholders noted capability gaps, including the absence of GMP viral vector and mRNA production facilities, and the lack of large-scale GMP cell production facilities in Australia
Limitation in research and development facilities	• Stakeholders suggested Australia must accelerate research translation and commercialisation while sustaining its investments in synthetic biology research if the nation is to pursue synthetic biology-enabled opportunities in global markets
Lack of mature technology	• With large multinational pharmaceutical and vaccine manufacturers dominating global supply chains, Australia may be more competitively placed to focus on applying synthetic biology tools and workflows to develop next-generation medical products and solutions
Long time to market	• Human health applications require rigorous validation of their safety and efficacy through clinical trials, which slows time to market and contributes to their high development costs
Lack of social acceptance	• Misinformation related to COVID-19 vaccines highlights the need for ongoing public engagement and social research regarding the risk and regulation of synthetic biology-enabled health solutions • Developing public trust and meeting high regulatory standards may be challenging for environmental applications that require environmental release of GMOs

Source: CSIRO (2021). A National Synthetic Biology Roadmap.

B.12. Example 4: synthetic biology (2/2)

Australia

	Recommendations/actions for creating an ecosystem synthetic biology (2020–25)
Translation support (investment and funding for infrastructure use)	• Focusing translational investments towards high-value, low-volume applications that could be commercially feasible before 2030 could help to attract additional private co-investment and accelerate the commercial validation of synthetic biology approaches within the Australian context • Bio-incubator programmes often offer competitive grants to enable affordable access for startups – funding should consider the startup's ability to demonstrate commercial, social, or environmental impact in the short term
(Lack of) shared infrastructure	• Providing project-based grants that support businesses to access bio foundry services could help to develop a sustainable pipeline of collaborative projects in Australia
Attract international partnerships	• Australian governments could consider public–private partnerships to accelerate the development of scaled biomanufacturing operations in Australia, with individual companies or through the development of a contract manufacturing facility
Foundational ecosystem enablers (leadership and governance, industry–research collaboration, and skills development)	• L&G: Establishing a bioeconomy leadership council would signal that the bioeconomy – and synthetic biology capabilities – are an important part of Australia's future (case study: UK Engineering Biology Leadership Council) • Contribution to international protocols and standards: ensuring that Australia contributes to developing and upholding international standards, protocols, and ethical principles associated with synthetic biology
2025–2040 actions	• Shift in investment: an effective form of government support during this time could be co-investment in industry projects rather than investing in further shared infrastructure • Integration in the Asia-Pacific supply chain: by 2030, early successful Australian startups, and Australian businesses prepared to be early adopters of synthetic biology outputs, should aim to be deeply integrated with supply chains in the Asia-Pacific region • Australia could position itself as an established biomanufacturing destination and provider of quality synthetic biology products and componentry for multinationals, SMEs, and startups in the Asia-Pacific region • Established research bio-foundries should aim to be financially sustainable, achieving full cost recovery for services offered to mature industry clients

Source: CSIRO (2021). A National Synthetic Biology Roadmap.

About us

Cambridge Industrial Innovation Policy (CIIP)

Cambridge Industrial Innovation Policy (CIIP) is a global, not-for-profit policy group based at the Institute for Manufacturing (IfM), University of Cambridge. CIIP works with governments and global organisations to promote industrial competitiveness and technological innovation. We offer new evidence, insights, and tools based on the latest academic thinking and international best practices.

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