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The role of **basic research** in **deep tech**

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The role of basic research in deep tech. A policy-oriented scoping review of the literature

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EXECUTIVE SUMMARY

Deep tech is viewed as central to addressing Europe's competitiveness, innovation, and security challenges. This report synthesises insights from a scoping review of academic and policy literature on the role of basic science in enabling deep tech development and the conditions that sustain its translation into innovation.

The term **"deep technologies"** refers to early-stage, science- and engineering-based innovations grounded in fundamental advances in areas such as materials, biotech, quantum, and fusion. They are typically hardware-centric, long-cycle, and high-risk, requiring strong ecosystems that connect discovery to market. Because most deep tech originates from research, universities form important seedbeds of deep tech innovation, providing the knowledge, talent, and infrastructure from which new solutions and ventures emerge.

This review focuses on the role of basic science in deep tech. What we understand by "basic science" has changed over time, alongside evolving research and innovation policy paradigms. For this report, **"basic science"** is defined by three characteristics: (i) it investigates phenomena at a fundamental level; (ii) it generates broadly applicable, foundational knowledge that supports multiple uses and sectors; and (iii) it expands the scientific frontier. The current emphasis on deep tech has renewed and elevated the importance of basic science as the foundation from which deep tech ultimately emerges. Expanding our fundamental understanding, pursuing discoveries, and enriching the shared knowledge base through basic science are here seen as essential preconditions for the development of transformative deep technologies.

The review identifies three conditions for basic science to flourish and be translated into deep tech innovation:

1. Sustained investment and protected spaces. Because the benefits of basic science are uncertain and often unfold over long time periods, basic science needs predictable, long-horizon funding and "protected space" – i.e. institutional, financial, and intellectual autonomy insulated from short-term political and market pressures – to pursue uncertain, fundamental lines of inquiry. This is ensured by e.g. tenure systems, block grants, and long-horizon research funding programmes that allow for the slow accumulation of knowledge that ultimately seeds deep tech breakthroughs. Overprogramming or oversteering of research, especially when coupled with short-term KPIs, risk crowding out the exploratory, curiosity-driven search that is an important element of basic science and thus of deep tech innovation.

2. Institutional diversity and balanced research portfolios. Evidence shows that national research strength correlates with the breadth of scientific fields rather than the concentration of funding. In other words, scientifically leading nations are highly diversified across a broad range of scientific fields. Moreover, diverse institutional arrangements and a heterogeneous set of funding instruments – including e.g. investigator-led grants, centres of excellence, and mission-oriented grants – sustain resilience and renewal in the scientific base. Excessive focus on narrow priorities or "picking winners"-strategies can increase vulnerability to hype-driven cycles and erode the exploratory capacity on which transformative innovation depends.

3. Effective translation and diffusion mechanisms. Scientific excellence and commercialisation are complementary, not competing. Studies show that entrepreneurial activities and industry engagement can in fact enhance research novelty and impact. Universities play a pivotal role in supporting the translation of science through mechanisms such as joint R&D, consultancy, contract research, and researcher mobility, as well as through the innovation ecosystems in which they nurture deep tech startups.

In summary, basic science is both the foundation and the flywheel of deep tech innovation. Its vitality depends on long-term investment, plurality in research institutions and agendas, and effective translational interfaces that connect scientific discovery to deep tech innovation and, ultimately, societal impact.

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1. Introduction

1.1. Background and aims

This report presents a scoping review of the role of basic science in the development and scaling of deep tech.

It was commissioned by the Royal Danish Academy of Sciences and Letters, the Carlsberg Foundation, the Danish National Research Foundation, and the Independent Research Fund Denmark, and prepared by researchers at the Centre for Technology Entrepreneurship (DTU Entrepreneurship), Technical University of Denmark (DTU).

The purpose of the review is twofold. First, it aims to inform the preparation of a parallel session at the ASCEND conference, held under the Danish Presidency of the Council of the EU in November 2025. Second, it is intended as a knowledge resource for the commissioning partners to support future policy discussions.

The review explores how basic science underpins Europe's capacity to generate transformative deep tech. It highlights the importance of sustained investment in fundamental research as a foundation for deep tech ambitions and in shaping Europe's long-term innovation potential.

More specifically, the review defines deep tech and describes its reliance on scientific advances rooted in basic science. It examines the pathways through which basic science contributes to scalable technologies and ventures. Finally, it identifies key enablers of basic science and its translation into deep tech innovation.

1.2. Approach

This report presents findings from a scoping review of academic and policy-oriented (also referred to as "grey") literature. The aim was to provide an overview of existing knowledge on how basic science enables the development and scaling of deep tech innovations, and to distil insights relevant for policymakers, research funders and other actors in the innovation ecosystem.

A scoping review was chosen as the methodological approach given the broad and interdisciplinary character of the topic, the emergence of new concepts such as "deep tech," and the diversity of available sources, spanning academic publications and grey literature. The purpose of the review is to inform policy discussions, not to provide a definitive or exhaustive account of all evidence.

The review applied an inclusive understanding of science, covering all scientific fields from STEM to the social sciences and humanities.

Publications were identified through iterative search string development (with the aid of ChatGPT-4o Plus) and systematic searches in Scopus (undertaken in August 2025), limited to publications from 2010 or later. The search was also limited to publications in English and within the subject areas 'Social Sciences,' 'Arts and Humanities,' and 'Multidisciplinary.' Table 1.1 provides an overview of the themes included in the search. Detailed search strings are available upon request.

Table 1.1. Literature search

Search strings, by theme *	Articles identified	No. of articles screened
Initial comprehensive search string based on review aims	427	(2,871)
The link between (basic) science and deep tech	25	(380)
The link between (basic) science and tech/innovation more generally	53	(1,512)
Rationale for public funding of (basic) science related to tech/innovation	177	(629)
The role of (basic) science in challenge and mission driven policies **	117	(359)
The link between research excellence and tech	38	(102)
The contribution of (basic) science to specific technology domains	88	(705)
The role of (basic) science in startups/spinouts **	122	(1,003)
The role of research funders	187	(641)
The link between (basic) science and competitiveness **	87	(729)

Search based on title, keywords and abstract (limitations year=2010+ and subject area=SOC, A&H, MULT).

** Search yielded too many irrelevant publications. Search was amended to exclude abstracts, i.e. limited to title and keywords.

Bibliographic data on a total of 8,931 articles were downloaded and manually screened for each search string, using Rayyan. A first manual screening (based on titles and keywords) yielded 1,321 publications for further consideration. 205 duplicates were removed, and then a second screening (based on abstracts) reduced the total set of publications to 514 publications. A third (full-text) screening led to the final selection of 139 articles for inclusion in the review.

Articles were excluded during the screening process if they did not provide substantive insights into the role of basic science in enabling deep tech innovation. Exclusion criteria included publications that: examined the economic impact of universities or research infrastructures without a specific focus on basic science; focused on graduate training, talent development, or university-industry engagement without explicit treatment of basic science; addressed research productivity, funding, or collaboration with only passing mention of basic science; concentrated solely on corporate R&D or technology transfer without reference to publicly funded research; described specific scientific or technological domains while only briefly mentioning basic science; presented purely descriptive bibliometric studies with no analytical insights; focused on education rather than research; communicated news bulletins (e.g. funding announcements) without relevant analytical content; were inaccessible (e.g. available only in languages outside the review scope). Additional articles deemed relevant for the study were identified via snowballing.

A search for grey literature was also undertaken to identify relevant policy publications, focused particularly on the EU context but also with selected references from the US debate. The search covered strategy and competitiveness packages, legislative and regulatory acts, programme frameworks and work programmes, budget and appropriation notes, formal evaluations and impact assessments, technology roadmaps and capability reviews, advisory/academy statements, and international communiqués. Searches were structured within official repositories, including the EU Commission Communications, Council Conclusions, Horizon Europe work programmes and ERC notes; OECD STI Policy Papers and the STI Outlook; national S&T leadership (e.g., OSTP and the National Science Board); and key public funding bodies. In addition, snowballing was used to uncover additional reports identified in flagship documents.

A final set of 200+ articles and 36 policy documents was manually coded to identify themes and insights relevant to the aims of the review, and findings were synthesised and reported.

In the following, we present the findings of the review. **Chapter 2** sets the stage by condensing key insights from the grey literature, focusing on the growing policy attention to deep tech and the role of basic science herein. **Chapter 3** examines academic literature on the role of basic science in deep tech, while also defining both these concepts and describing how they have evolved. Finally, **Chapter 4** identifies key enablers of basic science and its translation into deep tech innovation.

2. Deep tech in European innovation and competitiveness policy

Europe faces a persistent innovation dilemma: while it possesses world-leading scientific excellence, it underperforms in translating this strength into globally competitive enterprises and industries. Despite producing more scientific publications than the US (European Investment Bank. 2025, 227), Europe continues to lag in productivity growth, access to scale-up funding, and the capacity to transform research outcomes into marketable innovations (ERC 2023; European Investment Bank 2024). This paradox is further compounded by escalating geopolitical competition in strategic technological domains such as AI, quantum technologies, and biotechnology (NATO 2025; OECD 2023).

The capacity to innovate and to respond effectively to external shocks depends on sustained, long-term investment in research, skills, and infrastructure (OECD 2023). The rapid development and deployment of mRNA vaccines, for example, were made possible by decades of curiosity-driven research in RNA biology (Deborah 2021). Likewise, contemporary advances in quantum technologies, novel materials, and climate-resilient crops can be traced back to fundamental scientific inquiry.

Without sustained commitment to the upstream knowledge base, downstream innovation risks running dry. The key challenge, therefore, is how to more effectively connect Europe’s foundation of basic science to the scaling pathways of deep tech ventures.

The competitiveness gap is widening. European scale-ups raise roughly half the capital of their U.S. counterparts, forcing many promising firms to seek financing – and at times, relocation – abroad (European Investment Bank (EIB) 2024). The EIB attributes this gap to fragmented capital markets and limited pools of late-stage venture funding, both of which constrain the growth of deep tech firms emerging from Europe’s strong scientific base.

To address these challenges, the EIB calls for a deepening of European capital markets and a strengthening of the venture capital ecosystem through targeted public crowd-in mechanisms (European Investment Bank 2024), including completing the Capital Markets Union to support the scaling of European firms, providing patient and de-risked public capital, and building a stronger European domestic market and skills base, by reducing Single Market frictions and addressing talent and skills shortages as firms grow (Ibid.). The latter aligns with the Draghi Report (2024) which emphasises the removal of regulatory and administrative barriers that fragment EU demand, and with the Letta Report’s (2024) call to introduce a “fifth freedom” for the mobility of research, innovation, and talent.

While recent European policy documents, such as the Draghi Report (2024) and the European Startup and Scaleup Strategy (European Commission 2025a), primarily focus on addressing the barriers facing scale-ups, they also recognise the foundational role of science in sustaining the pipeline of ideas and knowledge from which new deep tech ventures emerge. The Draghi Report, for instance, stresses the role of universities and other research institutions as “central actors in early-stage innovation, generating breakthrough research and producing new skills profiles for the workforce” (p. 28), and highlights that Europe maintains a strong position in fundamental research and patenting (p. 28).

At the same time, the report cautions that “while the EU boasts a strong university system on average, not enough universities and research institutions are at the top” (p. 28), thereby underscoring the need to strengthen excellence in basic science across European research institutions. Furthermore, it calls for increased and more strategically focused investment in basic research, noting that “public spending on R&I in Europe lacks scale and is insufficiently focused on breakthrough innovation” (p. 29). Finally, the report concludes that the innovation pipeline remains weak at the stage of commercialising fundamental research, leaving “much of the knowledge […] commercially unexploited” (p. 29).

The Competitiveness Compass launched in January 2025 also called for intensified investment in research alongside improved conditions for innovators to bring new products to market more rapidly (European Commission 2025b). Similarly, the EU Startup and Scaleup Strategy (European Commission 2025a) released a few months later calls for increased and more effective efforts to translate research into deep tech innovation, addressing challenges of uneven university performance and fragmented support for the translation of research into ventures.

2.1. Takeaways from this chapter

Europe’s competitiveness depends on deep tech, and deep tech, in turn, rests on a broad and excellent foundation of basic science. Recent EU policy documents convey a consistent message: Europe must both ensure excellence in basic science across its research institutions and strengthen the commercialisation of fundamental research, particularly to enable the creation and scaling of new ventures.

The grey literature offers two main points of departure for this review. First, EU policy increasingly positions deep tech as a strategic lever for competitiveness. Second, while the upstream foundation of basic science is acknowledged as critical to deep tech development, the concrete mechanisms through which it contributes to and connects with scaling pathways remain underexplored, potentially posing challenges for the design of targeted and effective policy interventions. In the coming chapters, we therefore explore the role of basic science in deep tech as well as key enablers of basic science and its translation into deep tech innovation.

3. How basic science matters for deep tech

3.1. What is a "deep technology"?

"Deep technologies", or "deep tech", is an increasingly prominent concept in policy and investor discourse. Although no single, widely accepted definition yet exists, several formulations have been proposed within the fields of innovation and entrepreneurship, contributing to an emerging, working understanding of the term.

The term "deep tech" is used to describe early-stage technologies rooted in fundamental advances in science and engineering (Romasanta et al. 2021). It encompasses cutting-edge, science-intensive innovations across fields such as materials science, biotech, quantum and fusion (Raff et al. 2024). Moreover, deep technologies are typically centred on physical or hardware-based assets (Raff et al. 2024), and often integrate hardware and software components within complex systems (Romme 2022; Romasanta et al. 2021).

Deep technologies are frequently described as transformative (Raff-Heinen and Murray 2025) or disruptive technologies with the potential to reshape or create entirely new markets (Schutselaars et al. 2023; Kask and Linton 2023; Schuh et al. 2022). They are also often labelled as enabling technologies capable of unlocking advances across multiple industries (Raff et al. 2024; Walzer et al. 2024; Dionisio et al. 2023). They can drive radical innovation leaps, operational efficiency gains and sustainability benefits (Raff et al. 2024). Moreover, they carry the potential for substantial societal impact (Romasanta et al. 2021), particularly as many deep technologies address pressing sustainable development challenges (Nguyen et al. 2024; Schutselaars et al. 2023). Increasingly, deep technologies are also viewed as strategic assets for central national competitiveness and security (Raff-Heinen and Murray 2025)

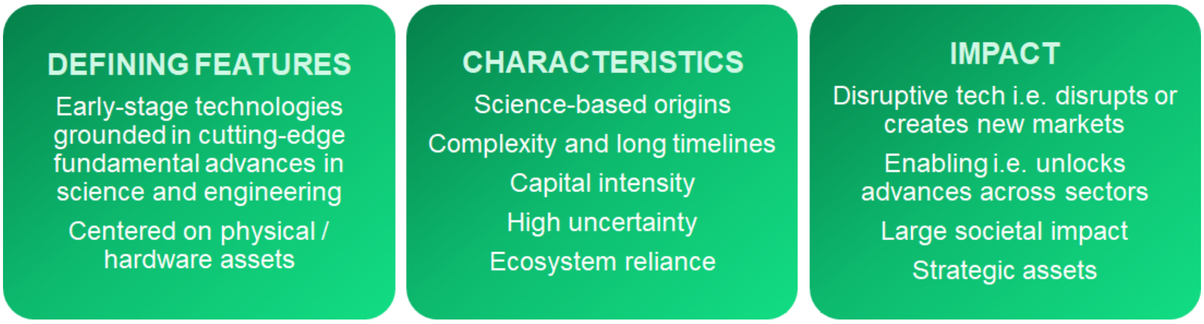
From this emerging definition, several core characteristics of deep technologies can be identified:

- **Science-based origins and founders.** Because deep technologies build on fundamental scientific and engineering advances, they commonly emerge from universities and other research-intensive organisations (Raff-Heinen and Murray 2025; Romasanta et al. 2021; Raff et al. 2024). They often rely on knowledge-intensive founders, including academic entrepreneurs (Dionisio et al. 2023).
- **Complexity and long timelines.** Deep technologies are highly complex and therefore ill-suited to standard "lean startup" approaches (Raff et al. 2024 Romasanta et al. 2021). They are R&D-intensive (Kask and Linton 2023; Schuh et al. 2022) and require long development horizons (Nguyen et al. 2024; Kask and Linton 2023; Dionisio et al. 2023; Romasanta et al. 2021), typically spanning 10 to 15 years from lab to market (Raff et al. 2024).
- **Capital intensity.** Deep tech ventures face substantial pre-revenue capital requirements (Borini et al. 2024; Schutselaars et al. 2023; Kask and Linton 2023; Dionisio et al. 2023; Schuh et al. 2022; Romasanta et al. 2021), often amounting to around USD 20 million in early rounds and exceeding USD 1 billion at later stages (Raff et al. 2024). As a result, they frequently depend on substantial public funding (Raff-Heinen and Murray 2025).
- **High uncertainty.** As disruptive technologies, they typically lack early market validation and face significant technological and market uncertainty (Raff et al. 2024; Dionisio et al. 2023), including ambiguity about potential applications and use cases (Borini et al. 2024; Walzer et al. 2024; Raff and Jovanovic 2022).

- **Ecosystem reliance.** Given their complexity and early-stage nature, deep tech ventures must develop technology, product, market, business model, and organisation in parallel (Schuh et al. 2022). They depend on broader ecosystems involving research institutions, government, lead customers, suppliers and complementary innovators (Kruachottikul et al. 2023; Romme 2022), as well as incubators and investors (Borini et al. 2024). Like the technologies themselves, these support ecosystems are often nascent and must co-evolve with the technologies they sustain (Borini et al. 2024)

These attributes contribute to high failure rates (Nguyen et al. 2024), particularly in the absence of appropriate, tailored support (Kask and Linton 2023).

Figure 3.1. Deep tech: defining features, key characteristics and impact



3.2. What is the role of basic science in deep tech?

Basic science is widely recognized as an engine of discovery that generates foundational insights capable of transforming technology and society (Farris 2020; Flexner and Dijkgraaf 2017; Collins et al. 2016). Its outcomes are inherently uncertain (Martin 1996), yet many of the most transformative technologies have originated in inquiries that initially appeared “useless”, that is, with no obvious practical application (Lehmann 2024; Flexner and Dijkgraaf 2017).

Despite this uncertainty, the payoffs for industry and society from investment in basic science are substantial (see e.g. Beck et al. 2017; Salter and Martin 2001; Rosenberg and Nelson 1994; Mansfield 1991; Jaffe 1989). Sustained investments in basic science account for a sizeable proportion of GDP (Flexner and Dijkgraaf 2017; Suresh and Bradway 2016), yield large long-term growth and welfare effects (Prettner and Werner 2016), and fuel technological progress, which accounts for most long-term economic growth (López-Rubio et al. 2025; Abramo and D’Angelo 2024; Moyo and Phiri 2024; Laverde-Rojas and Correa 2019; Suresh and Bradway 2016; Press 2013). It has therefore been described as one of the better long-term investments that governments can make (Rotman 2025). This point is underlined by a recent UK report on the public value of R&D, which concludes that the average pound invested in public R&D generating 8 pounds in net benefits for the UK over the long term, and highlights the role of curiosity-driven foundational science in transforming the economy and society (UK Department for Science, Innovation & Technology 2025).

The value of basic science for society was also underlined by the recently awarded Nobel prize in economic sciences to Joel Mokyr, Philippe Aghion, and Peter Howitt, for their contributions to explaining why science is central to long-term innovation and prosperity. While Mokyr’s work has been crucial in advancing our understanding of the feedback loops between scientific discovery and technological application, Aghion and Howitt’s model of creative destruction complements this by showing how new technologies replace old ones, renewing industries and driving productivity, provided societies remain open to new ideas and allow change. Together, the work of the three newly named Nobel laureates underscores that basic science is not a luxury but the generative engine of progress that expands the pool of useful knowledge that feeds innovation.

It is however worth noting that the contribution of basic science to technologies varies greatly across scientific fields and industries, and its economic effects depend not only on the underlying science but also on the volume and quality of downstream investments in activities necessary for the translation of science into innovation (Salter and Martin 2001), including the existence of effective government support (Block and Keller 2009).

Basic science findings have underpinned radical innovations such as CRISPR and mRNA vaccines (Lehmann 2024; Collins et al. 2016) and innovation in industry (Lo 2010), although the time lag from research is performed until it is applied in industry can take years or even decades (Du et al. 2019).

Salter and Martin (2001) identify six categories of benefit from basic science: (i) the generation of new knowledge, (ii) the development of new instruments and methodologies, (iii) the training of skilled researchers who carry both codified and tacit knowledge into other sectors, (iv) access to expert networks and information flows, (v) enhanced problem-solving capacities applicable in complex technological settings, and (vi) the creation of spin-off firms transferring research-based skills and capabilities into commercial contexts.

Thus, basic science environments play a critical role not only in generating knowledge, tools and methods, but also in training and talent development, cultivating skills such as systems thinking, mathematical modelling, and interdisciplinary problem solving that fuel innovation (Lehmann 2024; Flexner and Dijkgraaf 2017; Lauto and Valentin 2013; Giudice 2012). In addition, basic science is attributed with creating democratic and cultural value, as intellectual freedom in science is intertwined with freedom of thought and cultural development in democratic societies (Lehmann 2024; Flexner and Dijkgraaf 2017).

Turning to deep tech specifically, recent work underscores several key contributions of basic science:

- **Source of breakthroughs.** Because deep tech is grounded in scientific and engineering advances, industries such as quantum computing, synthetic biology, advanced materials, and biotech trace directly to curiosity-driven discoveries in fundamental research (Lehmann 2024; Farris 2020; Flexner and Dijkgraaf 2017). Deep tech breakthroughs frequently emerge serendipitously, as foundational insights cascade into unexpected applications (Lehmann 2024; Farris 2020).
- **Long-term pipeline.** Deep tech depends on a long-horizon pipeline in which basic science provides upstream exploration, translational research builds the bridge, and venture creation and development delivers downstream scaling (Raff-Heinen and Murray 2025; Collins et al. 2016).
- **Enabling environments.** Universities and other basic science organisations supply the talent, infrastructure, and early support – from labs and facilities to mentorship and networks – that nascent deep-tech ventures rely on (Borini et al. 2024; Raff et al., 2014).
- **Economic competitiveness & security**. Countries that sustain basic science funding retain a technological edge, as this cuts risk of brain drain and supports national competitiveness (Raff-Heinen and Murray 2025; Kruachottikul et al. 2023).

Deep tech is not separate from basic science but rather its visible, disruptive manifestation. First, it flourishes on the unpredictable downstream effects of basic science. Second, the quantum leaps (literally and figuratively) that power deep tech – e.g., in quantum computing, AI, biotechnology, space tech – are only possible because societies once invested in research that seemed remote, abstract, or even "useless". The challenge today is to protect and expand the ecosystem conditions (Dijkgraaf 2017) – long-term funding, intellectual freedom, and public trust – that allow curiosity-driven inquiry to seed the next wave of deep tech breakthroughs.

3.3. The historical evolution of the concept of basic science

Before turning to the definition of basic science, it is valuable to examine how this concept has evolved. "Basic science" is not a fixed, objective category, but rather a historically evolving concept. To better understand it, we briefly trace how definitions have changed over time.

Late 19th century: "pure science" vs "applied science". The categories of "pure science" and "applied science" crystallised during the late 19th-century industrial era as opposing moral economies – one valorising autonomy and integrity, the other embracing usefulness and commercialisation. Proponents of pure science defended "science for its own sake," seeking to protect it from conflation with applications, and emphasised truth-seeking over profit, independence from commercial influence, and distance from immediate utility. Others countered that applied science was genuine science, casting "pure science" advocates as elitist or impractical. In practice, however, boundaries were often blurred, for example, by a growing number of patenting scientists who demonstrated that scientific inquiry and utility were not mutually exclusive (Lucier 2012). At this time, technology was generally seen as subordinate to science – and associated with craft apprenticeships and a "shop culture", which stood in sharp contrast to the "school culture" of early science, although it gained in primacy as a result of the industrialisation and urbanization of the late 19th century (Larsen 2007; Kline 1995).

Early 20th century: Science as a driver of technological and economic progress. Perceptions of science shifted during World War I, when wartime mobilisation demonstrated its capacity to generate major technological breakthroughs (e.g., radio, sonar), cementing its status as essential to technological and economic progress (Katzir 2017). This changing perception was further reinforced in the interwar years and during World War II by advances in e.g. antibiotics, nuclear fission, synthetic materials, and electronics, as well as by the rise of industrial laboratories and "Big Science" during the interwar years (Kline 1995). As this utilitarian orientation gained ground, the ideal of "pure science" receded, and the term "basic research" came to prominence (Kaldewey and Schauz 2017). Thus, the concept of basic research or basic science did not arise from the pure science tradition, but rather emerged as a response to growing demands for usefulness, serving as a discursive bridge between promises of social utility and the inherent uncertainty of inquiry conducted without immediate applications in mind (Schauz 2014).

In his 1945 presidential advisory report, *Science – The Endless Frontier,* Vannevar Bush defined basic science as work "performed without thought of practical ends" (Bush 1945). Bush's report outlined a blueprint for federal support of investigator-led basic science, primarily conducted in universities, as essential to national health, security and prosperity, and cemented "basic science" as a rallying term that could unite scientists, policymakers, and the public around large-scale federal support for research (Pielke 2012).

Late 20th century: Basic science as a persistent political symbol. In the second half of the 20th century, the concept of basic science functioned as a powerful political symbol legitimizing investment in fundamental inquiry (Kaldewey and Schauz 2017; Godin and Schauz 2016; Schauz 2014; Pielke 2012; Godin 2011). It allowed advocates to promise both autonomy from immediate application and eventual usefulness, thereby accommodating the needs and interests of diverse actors in science and policy (Pielke 2012).

In the period following World War II, the concept of "technological innovation" emerged alongside that of basic science (Godin 2016). The so-called "linear model of innovation" also took hold, positing a sequential process in which basic science generated applied research, which in turn led to technological development and innovation. In fact, until the 1960s, technological advance was widely viewed as a downstream application of basic science; however, historical and empirical work by e.g. Edwin Layton and Walter Vincenti eventually recast technology as a body of knowledge in its own right (for a review of this work, see Larsen 2007). Subsequent research further emphasised the complementary, iterative nature of basic science and applied science or technology (Faria et al. 2024).

In the 1960s, a growing emphasis emerged on the outcomes of public investments in science. Against the backdrop of growing competitiveness pressures (e.g., from Japan) during the 1970s and 1980s, and later public budget constraints in the 1990s, policy focus shifted from the Vannevar Bush-inspired postwar sponsorship of autonomous basic science toward a stronger focus on university-industry linkages and more applied, market-oriented agendas. This redefined expectations of how basic and applied research should interact (Larsen 2007; Pavitt 2001; 1991).

Innovation was reframed as a holistic process encompassing development, commercialisation, adoption, and diffusion. This reconceptualisation supported systems-oriented views of innovation – such as "innovation systems", "Triple Helix" models, and later "innovation and entrepreneurial ecosystems" – in which basic science appeared as only one stage among many in the innovation process (Godin 2019). In parallel, growing attention was directed toward universities' direct and measurable contributions to innovation through industry collaboration, patenting, spinouts, and other so-called "third mission" activities (for a review of literature on this topic, see e.g. Norn and Alkærsig 2024). By the late 20th century, applied research and technology had gained cultural primacy over basic science, reflecting a broader societal shift that devalued basic science relative to its applications (Mody 2020).

21st century: basic science as part of the solution to societal challenges and to national competitiveness and security. Contemporary science, technology, and innovation policy increasingly converges on fostering "transformative innovation" that both addresses major societal challenges and strengthens economic competitiveness (Borrás and Edler 2020; Kuhlmann and Rip 2019; Simon et al. 2019; Sen 2014; Hellström and Jacob 2012), with deep tech often positioned as a pivotal vehicle for achieving both goals (Raff-Heinen and Murray 2025). The link between basic science and national competitiveness is hardly new (see, e.g., Giudice 2012), but it has acquired renewed urgency in light of the 2024 Draghi report on Europe's productivity and innovation gap vis-à-vis China and the US, and amid heightened concerns about European security, resilience, and long-term prosperity in a shifting geopolitical landscape.

Fulfilling the ambitions for Europe requires substantial investment in the creation of science-based innovations and industries (Etzkowitz 2012). Universities are expected to contribute to these ambitions by delivering societal value and solutions to grand challenges (Simon et al. 2019). While some firms do engage in basic research (Weick and Jain 2014; Rosenberg 1990), the responsibility for conducting basic science increasingly rests on universities. Because firms find it difficult to appropriate sufficient returns from investments in basic research, they tend to concentrate their resources on applied R&D that is more closely aligned with their core technologies and products (Arrow 1962; Nelson 1959). Yet, as previously discussed, basic science remains vital for driving advances across sectors and for underpinning economic growth and competitiveness. Consequently, societies cannot rely on firms alone to sustain investment in basic science; public funding for universities and research-performing institutions is therefore essential (Press 2013). This need is particularly acute today, as corporate engagement in basic research continues to decline – even though ample evidence shows that in-house basic science enhances firms' innovation performance by building absorptive capacity (i.e., the ability to identify, evaluate, and apply external scientific knowledge) and by providing direct inputs to internal innovation processes (Yu et al. 2024; Leten et al. 2022; Jung and Liu 2019).

As industry has shifted toward applied research and patenting over the past four decades, universities have become the primary source of basic science (Larivière et al. 2018; Arora et al. 2018). This shift, however, entails several risks, including depletion of the shared basic knowledge pool, misalignment between academic training and industry needs, and diminished translational capacity within firms as a result of weakened internal scientific capabilities (ibid.).

Consequently, increasing attention has been directed toward the role of universities not only in producing basic science but also in facilitating its translation into industrial innovation through academic entrepreneurship and robust, productive university-industry linkages (Kroll and Schubert 2024; Parker and Lundgren 2022; Miller et al. 2021; Wadhwani et al. 2017; Kruss et al. 2015; Etzkowitz 2012). Thus, the 19th-century view of basic science as practically and morally distinct from applied science and technology has been replaced by a picture of mutual interdependence, in which basic science, applied science and technology are seen as complementary and co-evolving. This perspective underpins the contemporary emphasis on challenge-led programs that aim to translate foundational discoveries into scalable, strategic technologies.

As the distinction between basic and applied science has been criticised for lacking clear, operational definitions and for oversimplifying the relationship between the two, other concepts have been proposed to describe the relationship between science and technology (see box 3.1 for examples).

Box 3.1. Other frameworks for understanding science

Notwithstanding the continued prevalence of the term basic research, other conceptual lenses have also shaped how science is understood and governed. We here highlight two of these concepts.

Curiosity-driven science emphasizes the motivation of the researcher – the pursuit of inquiry driven by intellectual curiosity and imagination rather than immediate utility (Farris 2020; Flexner and Dijkgraaf 2017). A subset of basic science (Salter and Martin 2001), it is often framed as the purest form of basic science and represents the "pursuit of useless knowledge," research conducted without regard to practical application, but which frequently yields unanticipated, transformative breakthroughs (e.g., radio, electricity, relativity, quantum mechanics) (Flexner and Dijkgraaf 2017). However, because the concept is rooted in moral and epistemic values, it has proven less operational in policy and funding contexts than the basic/applied distinction, which remains institutionally reinforced by the linear model and its linkage to utility. Moreover, framing curiosity-driven research as distinct from mission-oriented inquiry risks falsely implying that researchers responding to strategic calls cannot also be guided by curiosity.

Another enduring concept is **use-inspired basic science**. Stokes (1997) proposed that research can be classified along two dimensions: the quest for fundamental understanding and the consideration of potential use. Research that scores high on both dimensions falls within "Pasteur's Quadrant," named after the French chemist and microbiologist Louis Pasteur. This category of research is also referred to as "use-inspired basic research" and has had lasting appeal because it unites the quest for fundamental understanding in science with expected utility and immediate value for technological development and innovation (Anckaert et al. 2020).

Nevertheless, the basic/applied distinction has persisted (Kaldewey and Schauz 2017; Schauz 2014), largely because it has been institutionalised in OECD frameworks (e.g., the Frascati Manual), R&D statistics, and economic growth models (Pielke 2012; Godin 2011). Similarly, although the linear model of innovation has been faulted for failing to capture the complexity of innovation processes, it remains influential because it provides a compelling rationale for continued public investment in research: new knowledge generated through basic science can, over time, give rise to transformative technologies (Balconi et al. 2010).

3.4. Defining basic science

After briefly tracing how the concept of basic science has historically been used to rationalise and guide public investments in research and innovation, we now turn to how this concept can be understood today in the context of deep tech.

While the Technology Readiness Level (TRL) framework is often invoked when discussing deep tech, it is poorly suited for understanding the role of basic science. TRL was designed to assess the maturity of a specific technology within a defined application context (Héder 2017) and is therefore most informative for applied or translational stages of development (Tomaschek et al. 2016). Because TRL is application-specific, the same underlying technology can receive different TRL scores depending on the intended use (Héder 2017, p. 19). In recognition of these limitations, complementary frameworks such as Scientific Readiness Levels (SRL) have been proposed to better capture the maturity of research at earlier, more exploratory stages (see e.g. European Space Agency 2015). SRL distinguishes between fundamental, applied, and innovation readiness, noting that "for purely scientific projects, the level of technology readiness […] is not applicable in its pure form or has significant limitations" (Knar 2024, p. 7). However, SRL is not widely used, prompting the need to examine the defining features of basic science.

As discussed earlier in this chapter, OECD frameworks and R&D statistics have been instrumental in institutionalising the distinction between basic and applied science and thus contributing to its enduring role. The OECD's Frascati Manual (OECD 2015) provides the most widely adopted definitions (see box 3.2).

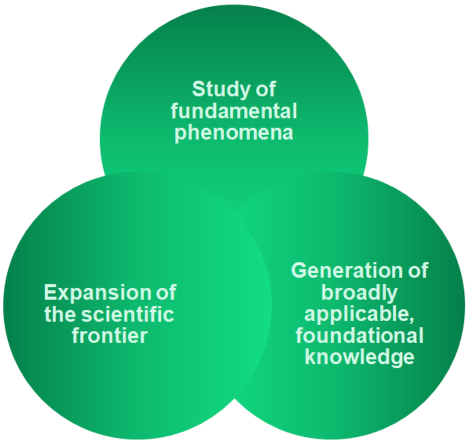
Box 3.2. Key definitions from the Frascati Manual

"**Research and experimental development (R&D)** comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge." (OECD 2015, p. 44, emphasis added)

"The term R&D covers three types of activity: basic research, applied research and experimental development. **Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. **Applied research** is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. **Experimental development** is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes." (OECD 2015, p. 45)

While the Frascati Manual remains a cornerstone for measurement and policy, its definitions were never meant to capture the evolving realities of science, technology, and innovation – particularly in fields such as deep tech, where the boundaries between discovery, invention, and application can be fluid. Building on the literature, we therefore propose a contemporary understanding of basic science based on three defining characteristics: the study of fundamental phenomena, the generation of broadly applicable, foundational knowledge, and the expansion of the scientific frontier (see figure 3.2). In the following, we briefly unpack these three characteristics.

Figure 3.2. Three defining characteristics of basic science



The study of fundamental phenomena. Basic science is often defined as research undertaken without a specific, practical end in mind. Anckaert et al. (2020, p. 2), for instance, describe it as "theory-driven research that follows a predictive and forward-looking logic, primarily conducted to understand phenomena without any specific application or end-use in mind." Similarly, the Frascati Manual (cf. box 3.2) refers to "experimental or theoretical work… without any particular application or use in view."

However, such intent-based definitions pose challenges. First, research motivations are difficult to observe empirically. Second, the presence of a potential end use does not necessarily make research less fundamental. Several authors have therefore introduced intermediate categories – such as "strategic" basic research – to describe fundamental inquiry oriented toward specific themes or problems (Bentley et al. 2015; Rip 2004; Salter and Martin 2001; Ziman 1994).

Rather than defining basic science by the absence of utility, it is more productive to define it by what it studies: phenomena at a fundamental level. As the Frascati Manual emphasises, basic science seeks "new knowledge of the underlying foundation of phenomena and observable facts." This understanding has deep roots (Kidd 1959). As Rosenberg and Nelson (1994) similarly argued that the bulk of university research is "fundamental" insofar as it seeks to understand elementary mechanisms, even when it is motivated by technological or practical concerns.

This view acknowledges that research can be both fundamental and problem-oriented. Indeed, U.S. federal agencies in the 1950s distinguished between "general purpose" and "special purpose" basic research (Kidd 1959), the latter roughly corresponding to what would today be termed thematic or directed research. Hence, a useful marker of basic science is not the motivation of researchers but the level of phenomena they investigate: research qualifies as basic when it seeks to understand fundamental mechanisms or principles underlying observed facts.

The production of foundational and broadly applicable knowledge. A second defining feature of basic science, we propose, is that it produces broadly applicable, foundational knowledge. Irvine and Martin (1984, p.4) defined the aforementioned concept of strategic research as "basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognised current or future practical problems." Similarly, Cohen (1948, as cited in Kidd 1959, p. 369) observed that some research is more fundamental than other work "simply because it affects a broader area, or because within its narrow area of applicability it has a deep and penetrating effect."

This dimension stems directly from the first: understanding phenomena at a fundamental level produces knowledge that is more general in scope and can serve as a platform for multiple applications. Vannevar Bush (1945, p. 2) articulated this clearly:

> "Basic research results in general knowledge and an understanding of nature by its laws. This general knowledge provides the means of answering a large number of practical problems. The scientist doing basic research may not be at all interested in the practical applications of his work yet the further progress of industrial development would eventually stagnate if basic research were long neglected. … A nation which depends upon other for its new basic knowledge will be slow in industrial progress and weak in its cooperative position in world trade, regardless of its mechanical skill."

This quote underscores that the breadth of possible applications of basic science results is key to understanding its wider effects on the economy, as described in section 4.2. General, reusable knowledge expands the range of potential technological opportunities. Klevorick et al. (1995) famously compared research to drawing balls from an urn, arguing that basic science increases the stock of knowledge – that is, the number of "balls" available to draw – and thus creates the conditions for new technological breakthroughs:

> "The most powerful and, over the long run, almost certainly the most important source of new technological opportunities has been the advance of scientific knowledge. ... It is widely believed that most significant technological breakthroughs can be traced directly to advances in basic general scientific understanding that occurred just prior to the breakthroughs." (ibid., p. 189)

Expansion of the scientific frontier. Finally, basic science can be understood as research that pushes the boundaries of existing knowledge. The notion of frontier research – popularised by the European Research Council (ERC) – captures this idea of work conducted at the forefront of scientific advancement (see e.g. Hörlesberger et al. 2013; European Commission 2005). The term, however, can refer to several related concepts: research at the leading edge of a field, research that is unconventional or high-risk, or research with potential for breakthrough discoveries (Larédo 2015).

Although true "breakthrough" status is typically established only in retrospect (see e.g. Wang et al. 2017; van Raan 2004), frontier research is distinguished by its novelty and its capacity to expand disciplinary or interdisciplinary boundaries. Schaper et al. (2025) define it succinctly as "the newest top science, made by scientists who are at the scientific frontier." Similarly, the European Commission's High-Level Expert Group (2005, p. 18) described frontier research as standing

> "… at the forefront of creating new knowledge and developing new understanding. Those involved are responsible for fundamental discoveries and advances in theoretical and empirical understanding, and even achieving the occasional revolutionary breakthrough that completely changes our knowledge of the world."
> The authors subsequently specified that "With frontier research, researchers may well be concerned with both new knowledge about the world and with generating potentially useful knowledge at the same time."

In sum, while basic science is a flexible concept that has been used in many different ways over time, we propose that it can be understood as research that seeks to understand fundamental phenomena, generates broadly applicable and foundational knowledge, and expands the scientific frontier. This multidimensional definition accommodates both curiosity-driven and use-inspired forms of inquiry and reflects the evolving role of science as both an epistemic and an economic engine, particularly in the context of deep tech, where fundamental discovery and technological application are tightly intertwined.

3.5. The role of research from the social sciences and humanities (SSH)

In this last section of this chapter, we zoom in on the role of research from the social sciences and humanities (SSH). SSH research plays an important but often overlooked role in the impact of science on technological development and society. The grand challenges facing society – including e.g., climate change, energy transition, healthy ageing, migration, liveable cities, and the economic-political effects of globalisation – are inherently complex and further complicated by power asymmetries between nations and differing stages of socio-economic development (Spaapen and Sivertsen 2020). Addressing such challenges requires contributions from multiple disciplines, with SSH research being essential for understanding context, values, behaviour, governance, and legitimacy. Yet, in practice, its role is frequently undervalued, with some governments even deprioritising SSH fields (ibid.).

Ongoing efforts to better capture the impact of SSH research (see e.g. Pedersen et al. 2018) have provided deeper insights into its contribution. SSH helps ensure that mission-oriented research remains focused on "what matters"; it situates problems within their social, cultural, ethical, legal, and historical contexts; and it provides a critical understanding of human agency and practice, thereby making technological solutions more effective and legitimate (Koenig 2019; Pedersen 2016). Embedding SSH perspectives early in technology development helps secure adoption, legitimacy, and alignment with societal goals (MacBryde 2025; Royston and Foulds 2021), underscoring the importance of interdisciplinary collaboration for unlocking deep tech's societal value and legitimacy (George et al. 2024).

For this report, we define interdisciplinarity according to Klein and Newell (1997, p. 393-394) as

> "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession […] and draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective."

However, effectively mobilising SSH research in interdisciplinary settings remains challenging. Projects nominally labelled as "SSH-inclusive" often fail to integrate SSH meaningfully, relegating its contributions to peripheral roles (Royston & Foulds 2021). A review of 127 recent funding programmes confirmed that SSH is frequently sidelined in initiatives presented as interdisciplinary or cross-disciplinary (Välikangas 2024). Even when SSH is included, it is rarely empowered to define its own knowledge-advancing questions; instead, it is steered toward instrumental contributions tied to pre-defined objectives, reducing its role to that of an add-on rather than a genuine partner in knowledge creation (ibid.).

A recent literature review further highlights enduring asymmetries between STEM and SSH research, manifested in perceived status hierarchies, power imbalances, and a tendency to assign SSH partners "service" functions. Combined with funding and review practices that struggle to evaluate multidisciplinary work, these factors help explain why SSH continues to be marginalised within projects nominally designed as interdisciplinary (Newman 2024).

Focusing specifically on the integration of SSH in European Framework programmes, Keraudren (2018) observed that European research policy has long prioritized technological research aimed at enhancing European competitiveness and innovation. Although SSH has evolved from a narrow focus on technology forecasting and assessment to encompass a much broader set of perspectives on technological and societal development, genuine SSH integration remains limited. EU-funded programmes continue to emphasize technological "fixes" to societal problems, often without adequately addressing the social conditions and transformation processes required to implement such solutions at scale (ibid.). The literature nonetheless identifies several pathways for strengthening collaboration between SSH and the natural and technical sciences, as summarized in box 3.3.

Box 3.3. Recommendations from the literature for strengthening STEM-SSH collaboration

Start with joint agenda setting and problem formulation. In the design of interdisciplinary programmes and projects, focus should shift from fostering "integration" to fostering "co-operation" on an equal footing (Koenig 2019). Include SSH from the outset – in agenda-setting and problem formulation – rather than as an add-on work package (Koenig 2019; Pedersen 2016). Ensure calls go beyond behavioural "human factor" fixes to include interpretive, culturally shaped, historically emergent perspectives (Pedersen 2016). Clarify what successful SSH integration / interdisciplinary collaboration looks like to allow for more effective design and evaluation of interdisciplinary collaboration (Newman 2024).

Build "interdisciplinary ecologies". Support bottom-up collaboration, recognising that most interdisciplinary ties emerge from researchers' problem-driven work, not just target funding (Pedersen 2016). Increase use of practical strategies for connecting researchers across disciplines, through e.g., networking events (Newman 2024), and invest in long-term integrative environments (e.g. interdisciplinary centres, durable teams, education) instead of short-term projects: build "interdisciplinary ecologies" (Pedersen 2016).

Provide appropriate funding. Back interventions with funding, e.g., using internal seed grants for interdisciplinary research, allocated on a competitive basis (Newman 2024). Ensure that calls consider and are inclusive of SSH aspects, and encourage SSH to compete for and lead projects and consortia (Koenig 2019).

Ensure meaningful research assessment. Practices for the evaluation of interdisciplinary projects must be improved (Keraudren 2018). Involve multiple SSH experts in assessment and evaluation; allow original SSH-led proposals and respect SSH autonomy and methods (Koenig 2019). Adjust peer review and evaluation to calibrate it to different modes of interdisciplinarity (multi-/inter-/trans-disciplinary) and cognitive distance between disciplines (Pedersen 2016).

Support effective interdisciplinary collaboration. Allow sufficient time and space for interdisciplinary collaboration (Koenig 2019). In building collaborative projects, resource teams of SSH scholars (not single individuals) with financial and operational autonomy, and earmark SSH budgets from the start (Pedersen 2016). Tackle asymmetries (e.g. in leadership, funding, dissemination, assessment) that tend to marginalise SSH within large programmes (Pedersen 2016).

3.6. Takeaways from this chapter

This chapter has traced how the concept of basic science has evolved, from its early role in legitimising postwar investments in autonomous research to its integration into current innovation and competitiveness agendas.

The overarching goals of public funding for science have changed little since the late 19th century: to foster economic growth, solve important societal problems, and strengthen national competitiveness. What has shifted over time is the perceived balance between basic science, applied research, and technology. In the current policy landscape, the emphasis on deep tech has renewed and elevated the importance of basic science – the foundation from which deep tech ultimately emerges. Expanding our fundamental understanding, pursuing discoveries, and enriching the shared knowledge base through basic science are essential preconditions for the development of transformative deep technologies.

Recognition of the importance of scientific capability for national competitiveness (Mazzoleni and Nelson 2009) is reflected in growing political focus on fostering basic science excellence across the world, including in China, where focused investments have led to marked increases in China's scientific performance (see e.g. Ke et al. 2026; Shih and Wagner 2024; Xie et al. 2014; Schneider and Norn 2023) as well as research-driven breakthroughs in e.g. high-temperature superconductivity, quantum communication, multiphoton entanglement, and stem cells (Huang 2018)

But what do we actually mean by "basic science"? In practice, the nature of research processes is difficult to characterise, and outcomes can be even harder to ascertain, given the well-documented time lags and challenges in fully capturing the impacts of basic research (Salter and Martin 2001; Martin 1996). For this reason, many categorisations of science – from the 19th-century ideal of "pure science" to Stokes' (1997) Pasteur's Quadrant – default to the presumed motivations of researchers. Yet this approach is problematic: motivations are difficult to observe, may shift over time, and can be strategically signalled. Calvert (2006) argued that classifying research by motives or aims is unreliable, gameable and provides no indication of the kinds of outcomes that can be expected.

Calvert (2006) further found that the same research project can be framed as either basic or applied at different times, as it may embody both fundamental and application-oriented qualities. Rather than defining basic science by its distance from application, this chapter therefore proposed defining it by what it studies and produces. Three defining characteristics were identified: (i) it investigates phenomena at a fundamental level; (ii) it generates broadly applicable, foundational knowledge that supports multiple uses and sectors; and (iii) it expands the scientific frontier.

Finally, the chapter emphasised the crucial role of the social sciences and humanities (SSH) in understanding and guiding the societal embedding of deep tech. SSH research helps situate technological advances within social, cultural, ethical, and political contexts, thereby improving their legitimacy, adoption, and alignment with societal goals. Yet, despite growing rhetorical commitment to interdisciplinarity, SSH integration remains limited in practice, often confined to instrumental or peripheral roles.

Together, these insights underscore that deep tech development depends not only on excellence in scientific discovery but also on the institutional, epistemic, and societal conditions that allow basic science to connect productively with innovation. In the next chapter, we examine the conditions that must be in place for basic science to flourish and be translated into deep tech innovation.

4. Enabling basic science for deep tech innovation

Given the central role of basic science in enabling deep tech, this chapter examines the key conditions that support its vitality and effective translation into innovation. Specifically, it focuses on three critical enablers: sustained investment and “protected space” for basic research, balanced research portfolios, and effective translational mechanisms.

4.1. Sustained investment and “protected space”

Because the benefits of basic science are non-linear and often materialise years or even decades after the research is conducted, it depends on sustained investment, including sufficient and stable core funding (Suk et al. 2020; Öquist and Benner 2015). For example, energy technologies typically take around ten years to progress from scientific discovery to working prototypes and decades to reach large-scale deployment (Perrons et al. 2021). This underscores the importance of patient, long-term investment in basic science and its enabling infrastructures (Du and Wu 2016).

While the translation of basic science into market-ready technologies is often slow and uncertain, there are instances when accumulated knowledge can be rapidly mobilised once the right conditions align, for example, in response to emerging opportunities or crises. The swift development of mRNA vaccines against COVID-19 drew on decades of fundamental RNA biology, while the rise of quantum technologies illustrates how sustained investment in basic physics and materials research can suddenly give rise to new markets.

The industrial uptake of porous coordination polymers pioneered by the 2025 Nobel laureates in Chemistry – Susumu Kitagawa, Richard Robson, and Omar M. Yaghi – further demonstrates how long-term, curiosity-driven inquiry can form the basis for transformative applications once technological and societal enablers mature. Their pioneering work on metal-organic frameworks (MOFs), initially driven by a quest for fundamental understanding, now underpins multiple deep tech ventures developing new materials for energy storage, hydrogen purification, and environmental remediation. Kitagawa, who adheres to the principle of seeking “the usefulness of useless”, did not initially envision any specific application for MOFs. Yet today, highly promising applications are emerging, from containing toxic gases used in semiconductor production to capturing CO_2 from industrial plants and power stations (NobelPrize.org 2025). This trajectory exemplifies how foundational, curiosity-driven research can create the latent knowledge base from which deep technologies later emerge, often in unpredictable ways.

Basic science requires not only temporal continuity but also financial and intellectual security to pursue uncertain, long-term inquiry. Fundamental exploration risks being crowded out by narrower, application-oriented priorities and therefore depends on the flexibility to follow research paths unconstrained by immediate translational goals (Farris 2020). For this reason, basic science is said to depend on “protected spaces” (see box 4.1) to thrive – without them, it risks being undermined by short-termism (Hellström & Jacob 2012).

Box 4.1. Protected spaces

Rip (2018) argues that protected spaces play a crucial role in enabling science to flourish. These are institutional, material, and cultural arrangements that allow researchers to pursue systematic inquiry insulated from short-term political or market pressures. Such spaces are essential for scientific innovation because they enable scientists to engage with complex, uncertain, and long-term problems that might otherwise appear too risky (Whitley 2014).

According to Whitley (2014), “protected space” refers to the degree of discretion and time scientists have over how to use their resources and efforts before being required to produce publishable or externally valued results. It encompasses autonomy in choosing research problems, methods, and in managing funding and personnel. Protected space depends on stable, long-term funding and career security – conditions that may be provided through institutional arrangements such as tenure or block grants, or through long-term project financing. Flexible research time is also crucial, as it allows scientists to pursue unconventional or high-risk ideas.

Beyond resources and infrastructure, protected spaces require clear institutional boundaries, that is, formal and informal recognition that public research institutions and their scientists are entitled to operate according to their own cognitive and methodological norms (Rip 2018) and to retain autonomy over how resources are allocated and research assessed (Whitley 2014). When protected space is eroded – for instance by short project cycles, managerial control, or excessive evaluation pressures – scientists become less likely to undertake ambitious or unconventional work (ibid.).

However, protection does not imply isolation. Historically, protected spaces have emerged through the interaction of researchers, funders, and institutional structures. The challenge, as Rip (2018) notes, lies in balancing autonomy and accountability: preserving sufficient protection for independent, long-term inquiry while remaining responsive to societal needs and expectations.

Basic science also thrives within diverse institutional arrangements, meaning that it is conducted across a variety of settings (including, but not limited to, universities) and supported through multiple funding models and governance structures that complement one another. Such diversity ensures that basic research is not constrained by a single organisational model or short-term KPI cycle (Öquist and Benner 2015; Hellström and Jacob 2012). Examples include stable core funding for universities, national laboratories, and large research infrastructures; competitive investigator-led grants (such as those offered by the Independent Research Fund Denmark or the European Research Council); support for both small-scale projects and large research centres (e.g., Centres of Excellence funded by the Danish National Research Foundation); as well as use-inspired basic science programs in mission-oriented agencies (e.g., the DARPA model, see box 4.2) and translational initiatives that bridge toward application and commercialization (which we return to in section 4.3).

While seminal work on science funding has long emphasised the importance of heterogeneity in research and innovation instruments, current policy trends, particularly in the EU, often promote convergence around uniform priorities and funding models. This shift risks undermining institutional diversity and eroding the “safe havens” that sustain basic science, as block funding gives way to narrowly defined project and program funding (Hellström & Jacob 2012).

Box 4.2. DARPA-type models for funding research and innovation

The DARPA model

The policy shift toward transformative and mission-oriented research and innovation (e.g., (Robert and Yoguel 2022; Wanzenböck et al. 2020; Diercks et al. 2019; Sen 2014) has renewed interest in the so-called DARPA model of funding. The Defense Advanced Research Projects Agency (DARPA), a U.S. Department of Defense agency established in 1958, funds high-risk, high-reward R&D projects intended to generate breakthrough technologies for national security (Sen 2017). Variants of the DARPA model have since been adopted in other U.S. domains, including homeland security (HSARPA), intelligence (IARPA), energy (ARPA-E), health (ARPA-H), and climate (ARPA-C).

The appeal of the DARPA model lies in its consistent record of producing impactful technological breakthroughs that have become foundational for entire industries (Carleton and Cockayne 2023). Notable examples include contributions to the development of the internet, satellite technology, GPS, mRNA vaccines, stealth technology, lasers, and robotics (DARPA 2025).

The DARPA model illustrates how basic and curiosity-driven research, when coupled with flexible funding mechanisms, can seed transformative deep-tech innovation (Mervis 2016). According to a former DARPA director, four factors underpin its effectiveness: decision-making autonomy, operational speed, fixed-term programme management, and strong connections with leading figures in research and industry (Gaind 2024). Key features include encouragement of risk-taking in basic science – even when outcomes are uncertain or lack immediate application – and reliance on programme managers with a high degree of autonomy to run temporary, time-limited programmes (Mervis 2016).

Programme managers play a pivotal role in assembling temporary project teams around selected high-risk topics with clearly defined targets. These teams combine internal staff and external collaborators; projects showing insufficient progress toward their goals are terminated and resources reallocated. DARPA thus works through both focused projects and long-term technology development efforts of a more foundational nature. (Piore et al. 2019; Mervis 2016; Dugan and Gabriel 2013; Bonvillian and Van Atta 2011).

Recent analysis of the ARPA model suggests that its effectiveness does not derive from any single design feature but from the interaction of its mutually reinforcing elements, notably organisational flexibility, bottom-up programme design, discretionary project selection, and active programme management. Together, these enable agencies such as DARPA to pursue emerging technological opportunities that fall between traditional research and market mechanisms (Azoulay et al. 2019).

The DARPA model underscores the importance of organisational design in enabling pathways from basic science to scalable technologies. Lessons from DARPA and related programmes indicate that radical innovation requires balancing *isolation* (i.e. “islands” free from bureaucracy and operational constraints, where experimentation and failure are possible) with *connection* (i.e. “bridges” linking projects to users, policymakers, and funders to ensure adoption and scaling) (Sen 2017).

DARPA-type models in Europe

Several experiments with DARPA-style initiatives have emerged outside the United States, including in Europe. A pan-European example is the philanthropically-funded Joint European Disruptive Initiative (JEDI), aimed at mobilising disruptive technologies to address grand societal challenges (JEDI Foundation 2021).

At the national level, Tekes, Finland's innovation funding agency created in 1983 to support strategic technology development, was directly inspired by DARPA. By 2009, it had funded more than 2,200 projects before merging in 2018 into Business Finland, which shifted focus toward investment promotion rather than breakthrough R&D (Carleton and Cockayne 2023).

More recently, Germany's SPRIND agency was launched with approximately €1 billion over ten years to support radical, pre-market innovation. However, operating such an initiative within EU state-aid, procurement, and audit frameworks has proven challenging, prompting calls for regulatory exemptions to preserve autonomy and speed (Rinke and Nienaber 2021).

The UK Advanced Research and Invention Agency (ARIA), established in 2023 with a ten-year budget and modelled on DARPA (Gaind 2024), concentrates authority in a small number of programme directors to minimise bureaucracy and allow independence (ARIA 2025). Although the initiative has been positively received, concerns remain that ARIA is below the critical scale needed for transformative impact, insufficiently linked to wider innovation-system dynamics, and lacks a strong demand-side pull akin to the U.S. Department of Defense's procurement role (Lewton 2023).

In their study of the DARPA model, Azoulay et al. (2019) identified several challenges to replicating the DARPA model elsewhere: measuring long-term transformational outcomes; balancing autonomy and accountability; recruiting and retaining high-quality programme managers under term limits; maintaining organisational culture amid turnover; and ensuring effective technology transition to markets. Ultimately, ARPA-type agencies should be seen not as substitutes for basic or applied research programmes but as complements within a diversified innovation ecosystem, bridging the gap between discovery and deployment

4.2. Balanced research portfolios

A recurring debate in science and innovation policy concerns how to balance support for a broad spectrum of disciplines and research topics against the concentration of funding in a limited number of priority areas. The effectiveness of the latter approach depends heavily on policymakers' and other stakeholders' capacity to identify the "right" topics and anticipate where future breakthroughs may occur – an inherently uncertain task.

Both policymakers and investors are also prone to "hype cycles", in which emerging scientific or technological domains attract disproportionate attention and resources, not always warranted by their demonstrated or likely future societal value (Robinson et al. 2021). Europe's deep tech strategies are similarly vulnerable to such hype-driven dynamics, underlining the importance of balanced narratives and reflexive governance in setting research and innovation priorities (ibid.).

Philanthropic funding provides a useful example: it has been criticised for steering research toward narrowly defined technological "silver bullets" rather than broader societal challenges (Fajardo-Ortiz et al. 2022). This focus risks underinvestment in foundational basic science – the domain that has historically generated the breakthroughs underpinning subsequent technological and industrial development (Gigerenzer et al. 2025; Fajardo-Ortiz et al. 2022). In fields where basic research remains underdeveloped, weak conceptual and methodological foundations can undermine applied work, as gaps in theory or understanding hinder progress. It is often assumed that the necessary basic science "exists elsewhere," but this is not always the case (Ellaway and Hecker 2022).

As early as the 1990s, Pavitt (1991) argued in his seminal article "What Makes Basic Research Economically Useful" that science funding policy should emphasise a broad base of support for basic research rather than selective investments in particular technologies. He critiqued the tendency to frame science policy narrowly through a “public good” or “market failure” lens, which overlooks the complex, field-specific, and often person-embodied linkages between science and technology. Pavitt found little evidence of economies of scale in basic research, concluding that concentrating resources into a few large, “strategic” fields or institutions is not necessarily more effective (in line with later work by e.g. Bloch et al. 2016). In other words, “bigger” is not necessarily “better” when it comes to science funding.

Pavitt (ibid.) also warned that the evidence underpinning selectivity and concentration strategies has been overstated, arguing that such approaches tend to underestimate the indirect contributions of science – for example, through the training of skilled researchers, methodological advances, the development of instruments, and the mobility of talent across academia and industry. Moreover, he highlighted the value of “unprogrammed” research in generating near-term innovation, citing studies such by e.g. Edwin Mansfield, who found that around 10% of the critical knowledge inputs to major industrial innovations originated from unplanned basic science conducted within the previous decade – benefits that would not, Pavitt argued, be likely to arise under a narrowly programmatic approach.

Empirical evidence also indicates that national competitiveness in global technology markets is correlated with maintaining a broad and diversified scientific knowledge base. Using a bibliometric, network-based analysis of 1996-2012 citation data, Cimini et al. (2014) examined countries’ “scientific fitness” (i.e., the competitiveness and diversity of their research systems). They found that scientifically leading nations are highly diversified across fields, indicating that scientific success correlates with breadth rather than narrow specialisation. Less-developed countries, by contrast, tend to concentrate in ubiquitous fields, particularly focused on high tech. In the most scientifically advanced countries, research excellence extended well beyond high-tech areas to include e.g. the social sciences, humanities, and medical research. In summary, technologically leading nations are not narrowly specialised; they diversify across many scientific domains.

The authors concluded that diversification in research acts as a systemic enabler of innovation capacity, fostering excellence as a by-product. Broad-based support – spreading resources across many smaller grants – can therefore be more effective than concentrating funding in a few elite institutions or selected research fields. This points to the need not only for targeted investments in strategic technologies but also broad-based, long-term investment in basic science to secure the knowledge base from which future breakthroughs can emerge. The study further showed that top-performing nations sustain substantial R&D investment, typically around 3% of GDP, over long periods.

For more detailed reviews of the literature on the role of variety and diversity in science and conditions for risk-taking and breakthrough science, we refer to previous policy-oriented reviews by, respectively Norn et al. (2021) and Norn (2019).

4.3. Effective translational efforts

To support and accelerate the translation of excellent research into societal and economic value, public funding for science must be accompanied by strong mechanisms for diffusion and translation – that is, mechanisms that connect scientific discovery to application, users, and markets (Kang and Motohashi 2020). Many university inventions are not market-ready (Landry and Amara 2012), and long-term investment in basic science must therefore be complemented by translational efforts that bridge the gap between fundamental inquiry and usable innovation (Flexner and Dijkgraaf 2017).

A country's ability to convert strong science into competitiveness depends not only on the quality of its research but also on its translation capacity – that is, the absorptive capacity of its industries and the effectiveness of its knowledge transfer systems (Abramo and D'Angelo 2024). Within these systems, universities play a central role as boundary institutions that link research, innovation, and society. They do so through a variety of commercial and non-commercial mechanisms, both formal and informal (Llopis et al. 2018; D'Este and Patel 2007; Debackere and Veugelers 2005): consultancy and contract research, joint R&D activities, training of industrial partners, and participation in advisory boards, to name a few (Klofsten and Jones-Evans 2000).

For an in-depth review of what universities can do to foster and support academic entrepreneurship, please see Norn and Alkærsig (2024). This recent review highlights that academic entrepreneurship is most effective when it protects researcher agency and research quality. Individual motives, autonomy, and skills are powerful drivers of engagement, and translation capacity therefore depends on the ability to incentivise researchers to collaborate with industry and commercialise their research. However, researchers' motivations differ according to their experiences, career stages, and disciplinary contexts, implying that uniform incentive schemes are rarely effective. Instead, researchers respond to different "bundles" of incentives, meaning that the key lies in balancing "gold" (financial rewards), "grace" (freedom to continue academic research), and "glory" (recognition and career advancement) (Walter et al. 2018).

The institutional scaffolding surrounding researchers is equally important. Translation capacity is shaped by universities' strategic commitment to innovation, departmental norms that value external engagement and innovation, and the quality of institutional support for collaboration and commercialisation – through e.g. technology or knowledge transfer offices (TTOs/KTOs), education and training in innovation and entrepreneurship, soft funding, incubator programmes etc. (Norn & Alkærsig 2024).

Universities are also embedded in regional and national ecosystems, whose performance and specialisation influence opportunities for innovation and entrepreneurship (Prokop 2022). Supporting the translation and valorisation of basic science thus requires effective alignment between university research strengths and the skills, resources, and interests of ecosystem actors – including e.g. investors, corporates, incubators, and public-sector partners (see Norn and Alkærsig 2024).

The review further emphasises the importance of complementarities between research and commercialisation. A substantial body of evidence documents a positive relationship between research performance and engagement in collaboration, innovation, and commercialisation (Larsen 2011; Perkmann et al. 2013; 2019). Entrepreneurial activities can enhance research by opening new exploratory paths, providing cognitive and material inputs, and stimulating both basic and applied inquiry. A growing body of research thus shows that scientific excellence and translation reinforce one another (Norn & Alkærsig 2024).

For example, Azoulay, Ding, and Stuart (2007) found that academic patenting often follows periods of intense scientific productivity, suggesting that commercialisation arises from fertile research environments rather than distracting from them. Similarly, D'Este and Perkmann (2011) showed that when engagement with industry is motivated by learning and access to resources, it strengthens scientific output in the long run by generating new ideas, partnerships, and funding opportunities. Recent longitudinal evidence further substantiates this complementarity: Fini, Perkmann, and Ross (2021) found that scientists who founded companies while remaining in academia achieved higher subsequent scientific impact, as entrepreneurial activity broadened their research horizons and inspired cross-disciplinary inquiry. Likewise, Kuckertz and Scheu (2024) showed that entrepreneurship enhances scientific performance – particularly within strong university entrepreneurial ecosystems.

Excellence in research and excellence in translation are thus mutually reinforcing. This relationship is especially pronounced among top-performing scientists, who often succeed in both domains due to greater resources, networks, and reputational advantages (Norn and Alkærsig 2024). Under the right institutional and cultural conditions, translation and entrepreneurship amplify rather than undermine scientific excellence.

Finally, researchers can take many different roles in the translation of their basic science, notably in the development of startups, which allows them to accommodate individual preferences and career goals while managing the impact on their academic work. Collaborating with "surrogate" or external entrepreneurs can help academic founders navigate the transition from scientific discovery to commercial venture by complementing their research expertise with business acumen, market insight, and managerial experience (Nikiforou 2023), while increasing the likelihood that academic inventions are commercialized successfully and that spinoffs achieve stronger early performance (Hayter 2013; Visintin & Pittino 2014; Lundqvist 2014). Surrogate entrepreneurs can take on roles that allow academic inventors to focus on their research while ensuring professional management and investor credibility (Franklin, Wright & Lockett 2001; Lockett, Wright & Franklin 2003). At the same time, maintaining the inventor's continued engagement often proves beneficial for the venture, as their deep technical knowledge and scientific legitimacy enhance innovation and collaboration within the team (Braunerhjelm & Svensson 2010). University-based intermediaries can help by providing researchers with access to networks of experienced entrepreneurs, industry professionals and investors (Norn and Alkærsig 2024).

4.4. Takeaways from this chapter

The literature reviewed emphasises that basic science is indispensable for industrial innovation and deep tech (Leten et al. 2022; Yu et al. 2024; Weick & Jain 2014), but ensuring that basic science thrives and is translated into deep tech innovation requires focused effort. This section highlighted several interlinked conditions that enable basic science to underpin deep tech development.

First, continuous and sufficient investment emerges as a central enabler that sustain the upstream wellspring. Because the benefits of basic science are uncertain and often unfold over long time horizons, stable, long-term, and flexible funding arrangements are essential. Basic science needs predictable, long-term funding and "protected space" – i.e. institutional, financial, and intellectual autonomy insulated from short-term political and market pressures – to pursue uncertain, high-variance lines of inquiry. Overprogramming or oversteering of research, especially when coupled with short-term KPIs, risk crowding out the exploratory search that deep tech depends on.

Second, the literature consistently shows the value of diversity and balance in research portfolios. Cross-national bibliometric analyses further demonstrate that scientific and technological leadership correlates with the breadth and diversification of national research systems rather than specialisation. Evidence cautions against narrow “pick-the-winners” strategies, particularly given the lack of evidence of scale economies in basic science. Care must be taken to avoid hype-driven prioritisation, which can misallocate resources. Moreover, stable block funding for universities and institutes and a variety of competitive funding models – from investigator-led grants to mission-driven programmes – appear to strengthen the resilience and adaptive capacity of science systems.

Third, effective translation and diffusion mechanisms mediate the relationship between scientific excellence and societal or economic impact. The evidence indicates that strong basic science and active engagement in translation of science are complementary rather than competing pursuits. Entrepreneurial and innovation activities can enhance scientific performance by generating new ideas, access to resources, and exploratory learning (Azoulay et al. 2007; D’Este & Perkmann 2011; Fini et al. 2021; Kuckertz & Scheu 2024).

Bolstering the translation of basic science into deep tech requires bridges, including effective models for university-industry collaboration and for nurturing university startups. Effective diffusion runs via a portfolio of formal and informal mechanisms (i.e. not just startups but also consulting, contract research, joint projects, mobility, advisory roles etc.) and depends on industry absorptive capacity.

Researchers can assume diverse roles in translating their science, and collaboration with surrogate or external entrepreneurs – who contribute commercial expertise, networks, and managerial experience – has been shown to strengthen the performance and credibility of academic spinoffs while allowing scientists to remain engaged in their research.

Taken together, these strands of research converge on a view of basic science as both dependent on and generative of its institutional and societal context. Long-term investment, institutional diversity, and effective translational interfaces jointly shape how fundamental research contributes to deep tech innovation and broader societal progress.

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