WHY VENTURE CAPITAL IS INDISPENSABLE FOR U.S. INDUSTRIAL STRATEGY

ACTIVATING INVESTORS TO REALIZE DISRUPTIVE NATIONAL CAPABILITIES

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Why Venture Capital Is Indispensable for U.S. Industrial Strategy:
Activating Investors to Realize Disruptive National Capabilities

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Introduction

The United States is in what the National Security Strategy calls "the decisive decade"[1] of intensifying transnational challenges, supply chain vulnerabilities, and geostrategic competition with China. Technology leadership will largely determine the United States' ability to prevail and prosper in the face of these challenges since the companies, products, and economic growth derived from advanced technology strengthen the economy, introduce innovative solutions to environmental and public health challenges, and provide sources of military deterrence and advantage. Over the past few decades, the U.S. innovation ecosystem has shifted. Instead of aligning with the strategic priorities of the U.S. government, companies are now more responsive to the demands of global consumers and businesses, often backed by venture capital. Consequently, the private sector has become less inclined to invest in hardware-based or capital-intensive projects, as these investments typically offer lower potential returns compared to the more lucrative software-focused ventures.

The critical technologies important for national security include many hardware-based or capital-intensive technologies such as advanced computing, advanced manufacturing and materials, biotechnology, communications and networking technologies, energy technologies, human-machine interfaces, quantum information science, semiconductors, and space technologies.[2] In fact, while many of these technologies would include software as part of a system, the only exclusively software technologies are artificial intelligence and the suite of tools that define cybersecurity. As much as 90 percent of venture capital investment today is in software, meaning that industries like AI and cybersecurity will be well funded.[3] However, to ensure adequate funding for the hardware-based, capital-intensive technologies such as advanced manufacturing and materials, semiconductors, energy technologies, quantum computing and space technologies, the U.S. government must be more proactive in attracting the required capital for commercialization.[4] All of these technologies are also dual-use—used by commercial companies and the military. Without adequate funding, the technology advantage of the U.S. military erodes.

1 White House, "National Security Strategy," October 2022, https://www.whitehouse.gov/wp-content/uploads/2022/10/Biden-Harris-Administrations-National-Security-Strategy-10.2022.pdf.

2 Executive Office of the President, "Critical and Emerging Technologies List Update," Fast Track Action Subcommittee on Critical and Emerging Technologies, National Science and Technology Council, February 2024, https://www.whitehouse.gov/wp-content/uploads/2024/02/Critical-and-Emerging-Technologies-List-2024-Update.pdf.

3 D2D Advisors, "Deep Tech Foundations," Digits to Dollars, April 20, 2023, https://digitstodollars.com/2023/04/20/deep-tech-foundations/.

4 See Appendix A for an expanded discussion of how this plays out in the quantum, energy, and biotech domains.

Among the available investment vehicles, venture capital stands out as the principal engine for commercializing promising new technologies. This paper aims to illuminate the pivotal role of venture capital in shaping U.S. industrial strategy, offering insights for policy makers and practitioners. Combining a longer time horizon and a higher risk appetite than other asset classes, venture capital rewards bold ideas, experimentation, and the assimilation of global talent. Because the U.S. government is unlikely to directly invest hundreds of billions of dollars to commercialize hardware-based technologies, it should instead shape incentives to attract private investors, especially the venture industry, which can be an indispensable partner in commercializing dual-use technology. To do so, however, it must understand the incentives that drive venture investment decisions to make hardware technologies of national interest more attractive. As a result of the failure to create a coherent commercialization strategy, much of federally-funded R&D remains in labs—or worse, is bought, stolen, or copied by adversaries who are more focused on the strategic advantages of developing these technologies than on achieving a high return on investment.[5] To avoid these failures, buttress American competitiveness, and effectively utilize the unique strengths of the venture capital ecosystem, the paper concludes by making five recommendations for aligning U.S. national technology priorities with venture capital incentives:

» Prioritize Promising Federal Research for Commercial Development

» Cultivate Entrepreneurial Founding Teams

» Create Transparency for the Federal Total Addressable Market (TAM)

» Demonstrate Technology Maturity, and

» Develop a Public Capital Framework.

With the right incentives to attract venture capital, the United States can ignite investor interest, mobilize hundreds of billions in private capital, and build the critical technologies essential for national security, economic prosperity, and global leadership.

5 Scott Pelley, Aliza Chasan, Aaron Weisz, and Ian Flickinger, "Global Intelligence Leaders Warn Against China's Technology Theft," *CBS News*, October 22, 2023, https://www.cbsnews.com/news/chinas-technology-theft-major-threat-fbi-head-warns-60-minutes/.

Racing with China for Technology Leadership

Several parts of the U.S. government have issued lists of the critical technologies for national security.[6] The same technologies recur across these lists: advanced computing, advanced manufacturing, AI, biotechnology, communications and networking technologies, energy technologies, human-machine interfaces, quantum information science, semiconductors and space technologies. Software is critical to the functioning of all of these technologies, but many are hardware-based or capital intensive, such as advanced manufacturing, materials and semiconductors. These dual-use technologies will create the industries of the future responsible for new companies, high-paying jobs, and military advantage.[7]

After World War II, the United States was the undisputed superpower in technology. U.S. entrepreneurs formed companies, and those companies set technology standards and became first-to-market. As a result, U.S. companies reaped the benefits of leading market share and enjoyed the "network effect," where the value of a product or service increases more with increased use.[8] While the U.S. still leads in most technology areas, there are a number which China now leads and which China challenges the U.S. lead (Figure 1).

6 White House, "National Strategy for Critical and Emerging Technologies," National Security Council, Trump Administration, October 2020, https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/10/National-Strategy-for-CET.pdf; White House, "Critical and Emerging Technologies List Update," National Science and Technology Council, Biden Administration, February 2024, https://whitehouse.gov/wp-content/uploads/2024/02/Critical-and-Emerging-Technologies-List-2024-Update.pdf; U.S. Department of Defense, "DoD Critical Technology Areas," Chief Technology Officer, Office of Strategic Capital, June 2023, https://www.cto.mil/osc/critical-technologies/; CHIPS and Science Act, Public Law No. 117-167, https://www.congress.gov/117/plaws/publ167/PLAW-117publ167.pdf.

7 See Appendix B for the importance of the dual-use technology race.

8 Wharton Online, "What is the Network Effect?," Wharton School, University of Pennsylvania (blog), January 17, 2023, https://online.wharton.upenn.edu/blog/what-is-the-network-effect/#:~:text=The%20network%20effect%20is%20a,back%20to%20the%20internet%20itself.

Figure 1. China Leads in Many Technologies Today and Challenges United States for Leadership in Others[9]

Technologies where China leads the United States today	Technologies where China is challenging the U.S. lead
» Cryptocurrency	» *Artificial intelligence*
» Small drones	» Biotechnology
» E-commerce (700 million users)	» Pharmaceuticals
» Electric (Li-ion) batteries	» Rocket launches into space
» LCD displays	» Quantum computing
» Electric vehicles	» Quantum sensors
» *Facial recognition software*	» Supercomputing
» Genetic data: genomics and medical histories	
» High-speed rail	
» Hypersonics	
» Mobile device manufacturing	
» Quantum communications (Micius)	
» Solar energy & solar panels	
» Telecommunications: 5G deployments	
» Ultra high-voltage electricity transmission	
» Wind energy	

There should be no doubt that China aims to displace the United States as the world's technology superpower because of technology's importance in fueling economic growth and in contributing to military advantage.[10] For the United States to not only compete effectively, but prevail and prosper, the U.S. government needs an industrial strategy for commercializing all of the critical technologies—not just the most financially lucrative ones like software.

The Changing Innovation Ecosystem in the United States

The innovation ecosystem in the United States has undergone significant changes since World War II, when Vannevar Bush fostered the idea that preeminence in science and basic research

9 Michael Brown and Pavneet Singh, research compiled from a variety of sources for briefings to U.S. government officials while serving at the Defense Innovation Unit (2017 - 2022).

10 Bloomberg News, "Xi Now Wants To Make China a Tech Superpower To End its Dependence on West," *Bloomberg*, March 2, 2021, https://www.bloomberg.com/news/articles/2021-03-01/xi-mobilizes-china-for-tech-revolution-to-cut-dependence-on-west.

leads to technology development that ensures national security.[11] Initially, the system was driven by federally-sponsored research and development (R&D). The Defense Advanced Research Projects Agency (DARPA), military service labs, the seventeen Department of Energy (DoE) National Labs, NASA, and the Federally Funded Research and Development Centers (FFRDCs) funded research at private companies and universities, which led to groundbreaking discoveries in microelectronics, advanced communications, computing, biotech, and aerospace, among others. Importantly, the DoD and NASA enabled U.S. firms to achieve a global lead in new industries like semiconductors and software because the research they supported was followed by revenue-generating contracts—the lifeblood for private companies—from the military or the Apollo program. Thus, the success of the innovation system depends both on research—often a federal government investment—and commercialization—which occurs mainly in the private sector.

However, the landscape began to shift as global markets for technology expanded. The influence of the U.S. government on technology development waned as billions of consumers set the direction of entrepreneurial and investment efforts. Concurrently, four critical trends emerged:

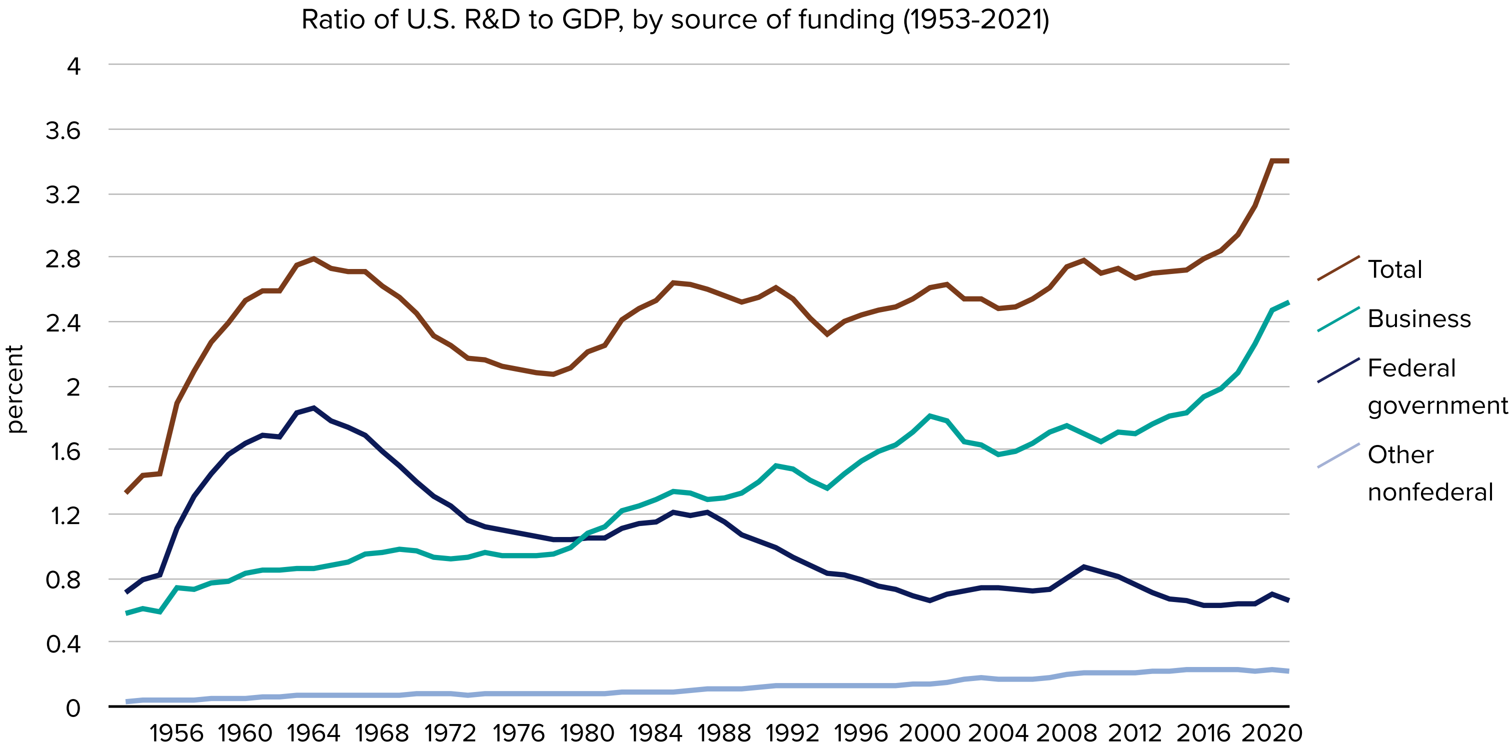
1. Decline in Federally Funded Research

Federal R&D spending peaked at nearly 2 percent of GDP in 1964 in the 1960s (Figure 2), driven by the space program and defense initiatives. In the post-Cold War era, federal R&D dramatically declined, sitting at just 0.66 percent of GDP in 2021. While private industry has stepped in to fill some of the gap, overall the U.S. R&D intensity has remained relatively steady at around 3 percent of GDP. Budget pressures and political gridlock further restricted federal research spending, often resulting in cuts across key research areas.[12]

11 Vannevar Bush, *Science, the Endless Frontier: A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, July 1945* (Washington: U.S. Government Printing Office, July 1945), https://www.nsf.gov/about/history/vbush1945.htm. Vannevar Bush created the system of federal R&D spending at universities "for the advancement of knowledge in the United States." As the science advisor to President Truman, Bush issued a famous report in 1945 which called basic research "the pacemaker of technological progress." The NSF, created in 1950, is Bush's legacy, cementing the idea that when the federal government funds basic research, both the nation's military and the economy benefit.

12 Gary Anderson and Francisco Moris, "Federally Funded R&D Declines as a Share of GDP and Total R&D," National Center for Science and Engineering Statistics, National Science Foundation, July 25, 2023, https://ncses.nsf.gov/pubs/nsf23339.

Figure 2. Business & Federal R&D Spending[13]



2. Corporate Short-Termism

As a result of the shareholder revolution of the 1980s, U.S. companies faced increased pressure to deliver short-term financial results. This pressure led to increasing focus on quarterly earnings, often at the expense of long-term R&D. Many companies shed hardware businesses in favor of more profitable software and service businesses, exemplified by IBM's sale of its PC business to Lenovo. As a consequence, vital manufacturing expertise has moved offshore, weakening U.S. innovation and creating national security risks, particularly in critical areas like electronics and defense supply chains.[14]

3. Rapid Advancements in Digital Technologies

Advances in software technology, such as modern programming languages, improved interoperability, global internet infrastructure, and smartphone miniaturization, have revolutionized the technology landscape. These developments accelerated the creation of software and internet-based companies, outpacing the growth of hardware or capital-intensive

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13 Gary Anderson and Francisco Moris, "Federally Funded R&D Declines as a Share of GDP and Total R&D," National Center for Science and Engineering Statistics (NCSES), 2023, NSF 23-339, https://ncses.nsf.gov/pubs/nsf23339/.

14 Michael Brown, Eric Chewning, and Pavneet Singh, "Preparing the United States for the Superpower Marathon with China," Global China series, Brookings Institute, April 2020, https://www.brookings.edu/wp-content/uploads/2020/04/FP_20200427_superpower_marathon_brown_chewning_singh.pdf.

industries. Consequently, investment shifted significantly toward software and consumer-focused products.

4. Rise of Venture Capital

The rise of venture capital as a key financing source for technology companies significantly shaped investment patterns. With a shorter-term investment horizon, venture capitalists primarily targeted biotechnology and IT, driven by the typical ten-year fund life. As a result, between 1995 and 2019, 83 percent of all venture capital investments flowed into life sciences and IT—mainly software—instead of capital-intensive hardware sectors like semiconductors and batteries.[15]

The cumulative effect of these trends has led to less federal research and less basic research aimed at future breakthroughs; shorter investment horizons, driven by corporations and venture capitalists; and the concentration of technology investment in life sciences and IT. While there is no shortage of capital in global markets or among U.S. investors, the challenge lies in channeling this capital towards the hardware-based or capital-intensive technologies which are important for national security.

U.S. Innovation Funding Is Increasingly Shorter-Term Focused

Most innovation capital today has a shorter investment horizon and, consequently, the composition of investments has increasingly shifted towards software. Government investment for R&D has the longest time horizon, but now totals only $200 billion (FY24) spent across twenty agencies. Government R&D is at the lowest level relative to GDP in a half century and represents about 20 percent of national innovation funding. Within the government, the largest R&D pool is the Department of Defense's budget of $143 billion,[16] where the average time horizon for new capability delivery is seven to twenty-seven years.[17]

Venture capital firms, who operate on a ten-year investment horizon, invested $354 billion in 2021.[18] This year, total venture investment is only half of what was invested in 2021; however,

15 PwC and CB Insights, "Money Tree Report, Q4 2019" January 3, 2020, https://www.pwc.com/us/en/industries/technology/assets/pwc-moneytree-2019-q4-final.pdf.

16 Laurie Harris et al, *Federal Research and Development (R&D) Funding: FY24* (Washington: Congressional Research Service, May 19, 2023), 16, https://crsreports.congress.gov/product/pdf/R/R47564.

17 William Greenwalt and Dan Patt, "Competing in Time: Ensuring Capability Advantage and Mission Success Through Adaptable Resource Allocation," Hudson Institute, February 2021, https://www.aei.org/wp-content/uploads/2021/02/Greenwalt_Competing-in-Time.pdf.

18 PitchBook Data, Inc., "Data on Venture Capital Funding in the U.S.," accessed September 20, 2024.

venture capital investment will rise again as public markets support more initial public offerings (IPOs) and corporations carry out more mergers and acquisitions (M&A). Venture capital is a relatively new source of national innovation funding, having increased tenfold in the past twenty years.

As government R&D declined, business R&D expanded to become the largest source of R&D investment (additive to investment from venture capital or private equity) at $600 billion annually (Figure 2). Business R&D investment has grown tenfold since federal R&D peaked in the 1960s and has doubled in the past twenty years alone.[19] While businesses have a range of investment periods, given increasing shareholder pressures for earnings since the 1980s, investment horizons are now shorter, averaging only five years.[20]

A much larger pool of capital, $5.8 trillion of private equity, is invested with an equally short investment horizon of three to five years.[21] If the average investment is held for five years, this amounts to over $1 trillion invested each year. However, private equity investments represent the purchase price of companies—not an investment solely in R&D—and are typically made to restructure a company's asset base, realize efficiencies, or modernize operations. Because private equity investment is so large, it should not be ignored; however, most of the private equity dollars are more appropriately directed at scaling production in existing industries like shipbuilding than for technology development.

The result of this increasing shift to shorter-term investment horizons is a change in both the risk levels and types of investments made: major breakthroughs become less likely and investment is overwhelmingly concentrated in IT, communication technologies, and life sciences. Over time and without offsetting measures, the United States runs the risk of falling behind China in many hardware-based or capital-intensive technologies, such as advanced materials and chemistries, quantum sciences and sensors, 6G, and 3-D printing. As government funding is constrained by the record federal deficit, influencing available private capital is a more pragmatic means to commercialize hardware-based, capital-intensive technology than direct U.S. government investment.

19 Ronda Britt, "Business R&D Performance in the U.S. Tops $600 Billion," National Science Foundation 23-350, September 28, 2023, https://ncses.nsf.gov/pubs/nsf23350.

20 Ariel Babcock, "Corporate Investment Timelines Are Shrinking, Is that a Bad Thing?" FCLT Global, March 4, 2021, https://www.fcltglobal.org/resource/corporate-investment-timelines-shrinking/.

21 "Global Alternatives Markets on Course to Exceed $30tn by 2030 — Preqin Forecasts," Preqin, September 18, 2024, https://www.preqin.com/about/press-release/global-alternatives-markets-on-course-to-exceed-usd30tn-by-2030-preqin-forecasts.

Incentives of the Venture Capital Industry

Relative to liquid investments such as stocks or bonds, venture capital offers higher potential returns in exchange for increased investment risk and longer lockups of capital. Venture investments are typically illiquid for the 10-year average duration life of a fund. Some venture investors may see partial return of capital during the life of the fund, but the average fund investment takes six to ten years to return capital depending on the stage of investment and the exit opportunities provided by the capital markets (through M&A or IPOs). Venture firms pool the risk of multiple investments; venture fund economics is based on one or a few investments generating outsize returns relative to others. In other words, for a venture firm that makes ten investments, perhaps only one winning investment "returns the fund"—meaning it generates enough return to pay back the entire fund's invested capital. In addition, this winning investment may generate a much higher return of twenty to forty times (or more) the original investment. For example, venture investor Peter Thiel made a 2,200 times return on his $500,000 early investment in Facebook, yielding $1.1 billion.[22] Typically, a few of the ten companies in a sample portfolio may generate a good return of one to three times capital invested, but most of the companies fail and return nothing. These economics have been termed the "power law," because one outsized capital return ensures the fund returns a multiple of capital to its investors regardless of the performance of most of its investments.[23,24]

To secure future funds and sustain their brand, venture firms must maximize returns on each fund. This is crucial for maintaining long-term relationships with institutional investors, who prefer to invest in a series of successive funds, ensuring ongoing participation and trust in the firm's franchise. The underlying power law means that venture firms seek to maximize the return on every investment.

Several business model characteristics contribute to higher returns and favor software relative to hardware: low capital intensity, low startup costs, and faster exits. Capital intensity is the capital required for product development, equipment for production, and inventories to support revenue growth. Low capital intensity favors software businesses much more than hardware businesses. Startup costs are the costs to initiate and develop the business. In the past decade, startup costs have dramatically shrunk for software, given widespread access to high-performance computing and networking through cloud services instead of buying and

22 Abe Othman, "What AngelList Data Says About Power-Law Returns In Venture Capital," AngelList (blog), June 17, 2020, https://www.angellist.com/blog/what-angellist-data-says-about-power-law-returns-in-venture-capital.

23 Sebastian Mallaby, *The Power Law: Venture Capital and the Making of the New Future* (Council on Foreign Relations Book, Penguin Press, 2022).

24 See Appendix B for an expanded explanation of the power law and its implications.

managing dedicated compute resources in a data center; open-source code components, or lego blocks, to build software sourced from open-source libraries instead of custom code; and remote-work contributions from lower-cost engineering locations due to global connectivity. All of these startup costs favor software relative to hardware. Additionally, software firms also tend to have faster time to liquidity through M&A or IPOs, which also generates better returns. Since software can also be developed more rapidly than hardware, software firms can demonstrate product-market fit sooner and scale faster. Finally, software has the potential to generate outsized returns by becoming a platform—such as a widely-used productivity tool like Zoom or a social network like Facebook—where network effects lead to increasing returns as more users adopt the product.

Although there are exceptions, hardware businesses are less likely to become a platform, carry more technical risk, require more time to develop, and require more capital for manufacturing equipment and inventories. From an industrial policy perspective, venture capitalists need no incentives to invest in software, a field in which the U.S. already enjoys a global comparative advantage. However, for hardware-based or capital-intensive industries, the private sector does not have sufficient incentives to invest in these riskier businesses. Given the opportunity cost of capital, no tax incentive for venture capital would be high enough to motivate venture capitalists to shift funds to a lower return profile.[25] However, if the hardware companies themselves were subject to a lower tax rate that boosted profitability and returns to investors, this would be an incentive for venture capital. In sum, absent a market intervention, venture capital investors will continue to invest much more in software like ad targeting and financial technology, rather than in technologies important for national security like new battery chemistries or hypersonic aircraft.

The implications for industrial strategy are clear: venture capital firms invest for outsize returns, not average returns. Absent economic incentives, they will not support national policy objectives such as supply chain resilience. Because venture capitalists already sufficiently fund software businesses, to motivate venture investment in hardware-based businesses, government incentives must increase the likelihood of an outsize return or reduce the technical risk sufficiently to enable an outsize return.

25 Joe Kennedy and Robert Atkinson, "Why Expanding the R&D Tax Credit Is Key To Successful Tax Reform," Information Technology and Innovation Foundation, July 2017, https://www2.itif.org/2017-rd-tax-credit.pdf. A reduction in the capital gains rate is likely to be a significant influence for corporations to make longer-term investments especially if the capital gains tax were variable based on the length of investment (rather than a single rate for an investment longer than one year). Likewise, improved R&D tax credits are also likely to motivate corporate behavior, even though unlikely to be significant enough to motivate VC behavior.

How VCs Evaluate Deals: Team, TAM, Tech

There are three basic factors that venture capitalists consider when making an investment to determine the likelihood of outsize returns: the founding team, the market size, and technology maturity. This first factor is the capability, experience and success characteristics of the founding team. A team is more likely to be successful than a solo founder and the team needs to have experience in the key functions required to build a business in addition to developing the core technology. Included in these would be a sound go-to-market strategy, curiosity about customer feedback, and the open-mindedness to shift the business idea to better achieve product-market fit. Additionally, the team needs the perseverance and team cohesiveness to overcome many obstacles in building a business. While unknowable at the time of an investment, patterns of behavior and previous business experiences are important determinants of successful behaviors.

Second, the total addressable market (TAM) of the business idea will be a critical determinant of an outsize return. If the market is too small or uncertain to build a large enough business valued at $1 billion or more, then the business idea will not be appropriate for a venture investment. The U.S. government's role in building a large market can be essential for dual-use markets, especially where the military can be a large customer. Good business ideas attract competition, so the market must be sufficiently large that even with multiple competitors, each competitor can grow to a size that yields a venture return of ten times or more of invested capital. Ideas which address an existing market are generally less risky than developing a new market or changing customer behavior.

Third, the technology must be developed beyond the basic research stage so that a resulting product or solution can be delivered in a timeframe consistent with the venture investment horizon of ten years or less. Venture capitalists avoid immature ideas which are not yet at a sufficient development level to yield a solution that customers can try within a few years. If an idea needs more years of research or large capital investments to prove its feasibility, this is a large obstacle to achieving outsize returns. Venture capital generally invests in proven technologies that the founding team can package relatively rapidly into a customer-ready solution to test the product-market fit.[26]

26 The U.S. government classifies technology maturity along a technologies readiness level (TRL) scale from one to nine, with one corresponding to basic research and nine meaning ready for mass deployment. VCs generally avoid lower TRL levels such as one to three.

Current U.S. Government Programs Supporting Team, Tech, TAM, and Capital

While venture capital has the potential to play a crucial role in advancing U.S. industrial policy goals, the government's current approach—despite its vast R&D funding, extensive research infrastructure, and technology transition initiatives—is not yet fully aligned nor optimized for attracting venture investment in commercialization efforts. There are promising federal programs that could be more influential in attracting private investment and strengthening the industrial base for critical technologies.

Founding Team

The talent in the science and technology enterprise across the U.S. government and within the subject matter experts of universities, labs, and other non-government R&D contract performers includes the most highly-trained professionals in their scientific fields. Additionally, in the 2022-2023 academic year, over one million international students enrolled in U.S. institutions and engaged in professional training contributing significantly to U.S. R&D efforts.[27] Most R&D and the resulting intellectual property is available for licensing through federal technology transition offices; universities, supported by federal funding, also make innovations available for license.

For investors, however, the availability of intellectual property (IP) and ability to license it alone is not sufficient since this is only one of many factors in building a business. In fact, retaining IP is no substitute for the talent responsible for making the discoveries being part of a founding team. This is especially true for hardware technologies where the fundamental research requires a deep knowledge of complex scientific principles and hands-on expertise in specialized equipment crucial for successful commercialization. This poses distinct challenges in spinning out federally-funded R&D. First, the U.S. government personnel system does not encourage technical experts to rotate from government to industry to advance their research. Second, at universities, most professors and researchers are discouraged from abandoning tenure-track positions to pursue startups. Third, many researchers are not trained in basic business development practices, nor do they have access to a network of investors, entrepreneurs, and industry mentors. In rare cases that researchers pursue startups, they would benefit by being paired with co-founders with complementary business skills.

Select areas within government are addressing challenges to technology transition. The National Science Foundation (NSF)'s I-Corps program, for example, is significantly reducing

27 Institute of International Education, "Open Doors 2023 Fast Facts," October 26, 2023, 1, https://opendoorsdata.org/annual-release/international-students/#data-highlights.

both the time and risk involved in transforming promising ideas from laboratory discoveries into market-ready technologies.[28] This program offers funding, training, and support, educating researchers on essential aspects of the technology transition such as customer engagement and market exploration. Both DARPA and NSF are initiating pilot programs with external partners who possess deep investment expertise and a track record in commercializing advanced technologies.

Total Addressable Market (TAM)

The existence of a TAM for a product or service is a dispositive factor for investors in considering whether to finance a company. However, for many emerging hardware technologies that are inherently risky, the markets for some are immature or non-existent. With that in mind, the U.S. government has several powerful tools to create new markets and open markets globally to ensure U.S. firms have access to overseas buyers, but these tools are not currently coordinated nor deliberately applied to nascent industries.

Contracts, Contracts, Contracts

The most effective market signal to stimulate demand for critical and emerging technologies is customers who commit to purchasing products. Meaningful and consistent contracts are the capitalist signal to current and future suppliers that more production and more production capacity are necessary.[29] To the extent that the U.S. government is a buyer for these technologies because of its importance to the national interest, the United States can be a market mover for new technologies just as it was in the 1960s when NASA and DoD provided contracts to semiconductor companies to support the Apollo program and miniaturize electronics for nuclear warheads. In 1965, the U.S. government bought 72 percent of the semiconductor industry output for the Apollo program.[30] This early and strong demand not only developed a nascent industry but also led to the mass production and cost reductions, which strengthened the computer industry and enabled widespread chip use in consumer products.

In recent years, NASA has played a critical role in supporting the commercial space industry, helping to establish the thriving commercial launch market through its early contracts. SpaceX was one of the key beneficiaries; on the brink of bankruptcy in 2008, the company received a $1.6 billion commercial cargo contract from NASA, which validated its reusable rockets as a

28 NSF's Innovation Corps (I-Corps™)," National Science Foundation, accessed October 4, 2024, https://new.nsf.gov/funding/initiatives/i-corps.

29 Michael Brown, "Capitalism Can Revive the Defense Industrial Base," *Forbes*, March 19, 2024, https://www.forbes.com/sites/mikebrown/2024/03/19/capitalism-can-revive-the-defense-industrial-base/.

30 Charles Fishman, "How NASA Gave Birth to Modern Computing—And Gets No Credit For It," Fast Company, June 13, 2019, https://www.fastcompany.com/90362753/how-nasa-gave-birth-to-modern-computing-and-gets-no-credit-for-it.

viable means of delivering payloads to the International Space Station.[31] Today, SpaceX has built a substantial business around space deliveries. Before securing the NASA contract, SpaceX had raised approximately $224 million in private funding. Since then, the company has raised nearly $9.5 billion and is now valued at $180 billion.[32] SpaceX is a prime example of how critical early contracts can be in attracting private capital; taxpayers did not need to fund the development of a space launch capability critical for national security. Additionally, SpaceX provided competition in the space launch industry, which further benefits the entire space industry as well as the government. To create redundancy, DoD and NASA funded the United Launch Alliance (a joint venture between Boeing and Lockheed Martin), which required almost $2 billion of taxpayer funding and whose launch costs are estimated at ten times the cost of a SpaceX launch. SpaceX has now launched more than 9,360 rockets and ULA has launched 161 rockets.[33]

Similar to NASA, the Department of Defense in particular can be a first mover in the technologies where it remains a large customer, such as satellite-based imagery and communications, autonomous vehicles, drones (airborne and maritime), energy-saving technologies, and energy alternatives to fossil fuels. Being a first mover simply requires the DoD to shift its budget from concentration in large defense platforms like F-35s and aircraft carriers to emerging technologies, and thereby provide a demand signal through meaningful contracts. Illustrating how infrequently the Department of Defense is using contracts to signal demand for emerging technologies, last year 99 percent ($406 billion) of defense contracts were awarded to incumbent defense companies while only 1 percent ($4 billion) of contracts were awarded to venture-backed companies.[34]

To show how important government contracts are to attracting venture investors, the Defense Innovation Unit (DIU), a strategic sourcing organization for DoD, found that for every $1 of prototype contract value awarded to a company, venture capitalists invest ten to twenty times that amount in additional equity capital.[35] Additionally, DIU enables rapid contracting at DoD for the businesses it places on contract, which further attracts more potential suppliers to DoD, ultimately helping to grow the defense industrial base and stimulate competition. There is no single more powerful action the U.S. government could take to attract venture investment

31 Eric Berger, "Without NASA There Would Be No SpaceX and Its Brilliant Boat Landing," *Ars Technica*, April 11, 2016, https://arstechnica.com/science/2016/04/without-nasa-there-would-be-no-spacex-and-its-brilliant-boat-landing/.

32 PitchBook Data, Inc, "SpaceX Funding Data," accessed September 10, 2024.

33 Julia Seibert, "ULA Vs SpaceX – A Detailed Comparison In 2024," Space Impulse, July 31, 2024, https://spaceimpulse.com/2024/07/31/ula-vs-spacex/.

34 Heather Somerville, "Investors are Betting on Defense Startups. The Pentagon Isn't," *The Wall Street Journal*, January 25, 2024, https://www.wsj.com/tech/defense-startups-risk-becoming-failed-experiment-without-more-pentagon-dollars-dc9e663a.

35 Defense Innovation Unit, "Annual Report FY2022," January 2023, https://downloads.ctfassets.net/3nanhbfkr0pc/5guJlhcMGwIgoop4z9r5QM/a724a6935a7e5a8d516cc58328e47796/DIU_Annual_Report_FY22_FINAL.pdf.

than making contract awards early to demonstrate market demand. The managing partner of a leading venture firm primarily invested in software shared with us that he would be equally interested in hardware investments if the government demonstrated its interest with contracts and orders. There are other actions the U.S. government can take to stimulate venture investment, but none are as powerful as issuing contracts.

Standards, Certifications, Testing

The U.S. government leverages various policy tools to establish standards, certify products, and inform regulations, ensuring that technologies can mature within a viable market infrastructure. Agencies such as the National Institute of Standards and Technology (NIST) play a crucial role in developing measurement standards and guidelines that ensure the quality and compatibility of new technologies across different industries. For instance, NIST collaborates with industry and academia to create standards for manufacturing and cybersecurity, ensuring interoperability and reliability as these fields evolve. Similarly, the Federal Aviation Administration (FAA) and NASA are pivotal in certifying propulsion technologies and aerospace innovations. These agencies conduct rigorous testing and certification processes to ensure that new technologies meet the necessary safety and performance standards, with the FAA's certification of new aircraft technologies ensuring their safety for public use.[36]

The Defense Sciences Office (DSO) at DARPA understands that technology will mature slowly, or not at all if certifiers are not engaged early. To bridge this gap, some Program Managers at DSO are meeting with regulators at the outset of projects and are also producing larger and varied samples to support early testing. This proactive approach ensures that as disruptive technologies such as quantum information sciences and synthetic biology mature, commercialization can occur with minimal friction and delay. Another benefit is signaling risk reduction to investors through the assurance of the quality, safety, and interoperability of products, thereby facilitating market adoption and increasing the likelihood of an outsize investment outcome.

Trade and Investment Policy

The United States has a long history of creating export markets to reach global consumers. Key to productive trade policy is harmonizing regulatory standards and certifications while also aligning new regulations. Trade agreements establish market-based norms, including

36 In biotechnology, the Food and Drug Administration (FDA) oversees the approval and regulation of new medical devices and pharmaceuticals, ensuring they meet stringent safety and efficacy standards before reaching consumers. Internationally, FDA approvals are highly respected and often accepted by other countries' regulatory bodies. For example, Switzerland recognizes medical devices with FDA approval, reflecting global confidence in the FDA's evaluation processes. Additionally, the European Medicines Agency frequently aligns its standards with the FDA, facilitating smoother market entry across both the United States and Europe. The acceptance of FDA-approved COVID-19 vaccines by many countries illustrates global reliance on FDA standards.

enforcement methods and potential remedies, which promote broader competition for larger markets. However, trade agreements typically focus on trade in established goods and services like agriculture, textiles, automobiles, and digital services rather than potential future products and services. Given the rapid pace of technology development and the industries they can spawn, U.S. trade negotiators must also lay the groundwork for trade in industries that do not yet exist.

Tech

Given the nearly $200 billion invested in R&D annually, the U.S. government is a bountiful source of disruptive technologies.[37] However, given the shorter-term and higher profitability incentives of venture capitalists, much of this research—some of it important for national security like new battery chemistries or advanced materials—will not be commercialized. Additionally, many research sponsors default to "fire and forget" modes, often allocating research spending without contemplating how to mature the technology beyond research.[38] Further handicapping academic researchers at U.S. universities, tenure policies tend to promote publications and citations over the commercialization of promising results. As a result, promising research suffers from deferred maturation and investors avoid engagement at earlier stages of technology development. The unintended consequence is that foreign state-backed actors with patient capital and longer-term strategic horizons are actively transferring U.S.-federally funded research overseas.[39]

Today the government is taking steps to counter this trend by emphasizing the practice of "use-inspired" research. Use-inspired research is strongly favored in the Inflation Reduction Act, the Bipartisan Infrastructure Act, and the CHIPS and Science Act, calling for program officials to design R&D programs around grand challenges. For example, the Department of Energy (DoE) programmatically encourages transitions from basic to applied research and then to demonstration and solutions at scale. DoE is enumerating grand challenges such as achieving commercial fusion energy development and sub-nanometer semiconductor development.[40] Thoughtfully-crafted programs such as ARPA-E, SCALEUP, Office of Clean

37 Laurie Harris et al, *Federal Research and Development (R&D) Funding: FY2024* (Washington: Congressional Research Service, 2023), 5, https://crsreports.congress.gov/product/pdf/R/R47564. Nearly $100 billion of the $200 billion in R&D funding is allocated to Basic ($45 billion) and Applied Research ($47 billion).

38 Michael Brown, "The Big Disconnect: Defense R&D and Warfighter Capabilities," Forbes, March 26, 2024, https://www.forbes.com/sites/mikebrown/2024/03/26/the-big-disconnect-defense-rd-and-warfighter-capabilities/.

39 Andrew Eversden, "Top Pentagon Research Arm Combats 'Aggressive' Foreign Investors," *C4ISRNET*, March 16, 2021, https://www.c4isrnet.com/industry/2021/03/16/top-pentagon-research-arm-combats-aggressive-foreign-investors/.

40 U.S. Department of Energy, "Department of Energy Announces $73 Million for Basic Research to Accelerate the Transition from Discovery to Commercialization," press release, September 11, 2023, https://www.energy.gov/science/articles/department-energy-announces-73-million-basic-research-accelerate-transition.

Energy Demonstrations, and the Loan Program Office provide significant resources to de-risk breakthrough technologies and increase their attractiveness to investors.

Similarly, the NSF was empowered by the CHIPS Act to create the Technology, Innovation and Partnerships (TIP) Directorate, the first new directorate at NSF in 30 years, TIP strives to shift the traditional research framework from being predominantly investigator-driven to a more collaborative, challenge-focused approach. TIP utilizes cooperative agreements which include performance milestones—a significant shift from the traditional NSF grant model. Demonstrating technology maturity significantly reduces risk and attracts private capital. Ideally, technology reaches a maturity level where successful development depends on execution rather than further invention.

Capital

Successful hardware-based or capital-intensive technologies require both capital and a longer investment horizon to realize commercialization. Dating back to the 1950s, the U.S. Small Business Administration (SBA) began licensing Small Business Investment Companies (SBICs) to enable private investors, such as venture capitalists, to leverage public funds for investments.[41] For example, when the United States built its semiconductor industry, SBICs provided capital to complement private funding for the capital-intensive industry. Additionally, government contracts guaranteed a customer, ensuring success for the industry and its suppliers.

At the end of the Cold War, SBICs became less necessary as private capital rushed into Silicon Valley and venture capitalists invested more in less capital-intensive businesses. To encourage small businesses to pursue R&D and commercialization activities, Congress created the Small Business Innovation Research (SBIR) program in 1982 and the Small Business Technology Transfer Program (STTR) in 1992.[42] Both were designed for small companies to receive up to $1.15 million over three years to advance promising research relevant to the missions of eleven federal departments and agencies.[43] Over the years, SBIR funding supported early efforts at prominent American technology companies such as Qualcomm and Symantec.[44,45] SBIRs and STTRs remain the primary government programs for small businesses to develop technology. The NSF even refers to its program as "America's Seed Fund."

41 Margaret O'Mara, *The Code: Silicon Valley and the Remaking of the World* (Penguin Press, 2019) 73.

42 U.S. Small Business Administration, "Birth and History of the SBIR Program," SBIR.gov. Accessed July 1, 2024. https://legacy.www.sbir.gov/birth-and-history-of-the-sbir-program.

43 U.S. Small Business Administration, "FAQs," SBIR.gov, accessed July 1, 2024, https://legacy.www.sbir.gov/faqs.

44 U.S. Small Business Administration, "Qualcomm Inducted into SBIR Hall of Fame," SBIR.gov, June 23, 2022, https://www.sbir.gov/success/qualcomm-inducted-sbir-hall-fame.

45 U.S. Small Business Administration, "Symantec Recognized by Small Business Administration," SBIR.gov, June 23, 2022, https://www.sbir.gov/success/symantec-recognized-small-business-administration.

However, with an annual appropriation of roughly $3 billion and award sizes still mostly capped at a small amount over an extended period of time,[46] SBIRs have been criticized as spreading too many small grants to companies with poor records of technology transition from R&D to production.[47] Ironically, many venture firms do not value SBIR grants when making investment decisions because of the low transition rate from R&D to production and the absence of firm purchase commitments from the U.S. government for companies receiving these grants. Only 1 percent of SBIR awards transition to programs of record, which are acquisition programs that have been formally approved and documented in the DoD's budgeting process, and which receive appropriations by Congress.[48] While the Air Force, through its AFWERX program, has led the way in reforming the SBIR program, this effort is too small-scale to develop capital-intensive technologies.

Two bright spots in the government's engagement with the venture industry are DIU and In-Q-Tel. As mentioned previously, DIU's prototype contracts not only place companies on DoD contracts rapidly but provide evidence of government market demand and attract private capital at ten to twenty times the dollar amount of contracts. In-Q-Tel, created by the CIA in 1999 (since re-named IQT), has grown into a global investment platform serving customers across the U.S. government and is a respected co-investor in the venture ecosystem given its strong technical diligence and market signaling that the technology, if proven, may find a large customer in the U.S. government. IQT's current portfolio includes a balanced mix of investments in hardware and software companies but, because of its modest budget, it is not a major funding source for hardware companies.

Recently, the U.S. government signaled attempts to nurture critical and emerging technologies by offering a range of loans and loan guarantees as well as a revitalized SBIC program. The U.S. Export Import Bank (EXIM), the official export credit agency of the United States, normally provides loans, loan guarantees, and insurance to established exporters like Boeing. Following the 2019 reauthorization of the bank, EXIM announced the creation of the China and Transformational Exports Program (CTEP) as well as the Make More in America Initiative (MMIA). CTEP aims to use loans and loan guarantees to support U.S. exporters facing competition from China and to ensure the United States remains a leader in critical and emerging technologies. MMIA uses EXIM tools to support U.S. manufacturing projects aimed at boosting domestic

46 This funding is not a separate annual appropriation, but a 3.2% tax on all federal R&D budgets exceeding $100 million and appropriated throughout the government since FY2017. The largest dollar amount is R&D spending at DoD.

47 Mary Gallo, "Small Business Research Programs: SBIR and STTR," October 21, 2022, https://crsreports.congress.gov/product/pdf/R/R43695. Data is mixed on transition rates. A 2019 DoD study found that 58 percent of SBIR/STTR Phase II recipients between FY1995 and FY2012 had some level of commercial sales by 2018.

48 Justin Krauss, "Tapping the United States Greatest Weapon: Innovation," J.P. Morgan Insights, September 20, 2024, https://www.jpmorgan.com/insights/investing/investment-trends/defense-tech-innovation-and-the-role-of-startups.

production, strengthening supply chains, and enhancing global competitiveness. Both are novel in providing large loans of $170 million or more to U.S. companies in speculative technology areas that are heavily capital intensive. Additionally, DoD recently created the Office of Strategic Capital (OSC) to leverage loans and loan guarantees aiming to ensure that component technologies—those that are critical for national defense but which are not end items the DoD would purchase—can be viable businesses. Additionally, OSC and the SBA are in the process of licensing a new generation of SBICs to invest in critical and emerging technology companies. To truly make an impact, this new generation should direct its efforts towards hardware and capital-intensive industries.

These loan programs follow in the footsteps of the DoE's Loan Program Office (LPO), which has $40 billion available in debt capacity for financing renewable energy, advanced nuclear energy solutions, advanced fossil energy, and vehicle manufacturing. Established in 2005, the LPO is credited with supporting Tesla's transition from a niche carmaker to a major player in the automotive industry.

Recommendations for Aligning U.S. National Technology Priorities with VC Incentives

To ensure the successful commercialization of critical technologies, aligning U.S. national technology priorities with venture capital incentives is essential. By bridging the gap between government-backed R&D and private investment, the United States can accelerate the development of deep technologies and in the process foster innovation and strengthen the industrial base.

Prioritize Promising Federal Research for Commercial Development

A first step in aligning national interests with private investment would be to prioritize the research for hardware that combines the most cutting-edge technology breakthroughs with the technologies of the highest national interest. However, there is no decision-making authority today within the U.S. government tasked to prioritize technologies for commercial development. The Office of Science and Technology Policy (OSTP), a Cabinet-level office at the White House with purview over research areas across the federal government, would be a potential office for technology prioritization. Once promising federal research has been prioritized, a government body with programmatic capability could ensure that the team, TAM, tech, and, if necessary, complementary capital are in place to stimulate venture investment for hardware-based technologies. A candidate for this programmatic responsibility would be the NSF's newly-formed TIP Directorate.

Cultivate Entrepreneurial Founding Teams

To create founding teams, TIP could build a network of entrepreneurs with different business-building skills and likely hire a complement of recruiting firms to expand this network. Naturally, the technical founder should be heavily involved from the outset to determine compatibility; team chemistry, in addition to complementary skills, is key to a successful founding team. TIP's budget should include salaries for these founding teams for a limited period of time while teams seek venture capital. If, for example, a business does not identify financing prospects after six months, then that is a signal that there is more work to be done with the team, TAM, or tech maturity to make it a likely venture investment.

A promising way to immediately expand the talent pool of researchers and entrepreneurs for these high potential businesses would be to reform immigration for technically qualified talent while simultaneously making significant investments in U.S. STEM training to train a competitive U.S. workforce. Foreign students and technical entrepreneurs have been a critical engine for U.S. success in science, technology development, and the formation of new ventures. Today, 55 percent of America's companies valued at $1 billion or more have first-generation immigrants as founders, including Uber and SpaceX,[49] and each of these companies has created on average 1,200 jobs per company.[50]

Create Transparency for the Federal TAM

Beyond assisting in forming a founding team, the government should make the federal TAM more transparent and, if possible, enlarge the TAM and provide visibility through contract awards. The President should set the expectation that government departments and agencies should work with TIP to increase the visible TAM for these prioritized technologies through securing government contracts (with supporting appropriations) or incentivizing government suppliers like defense primes with an R&D tax credit to write contracts for new technology suppliers. On a national level, the relevant government agencies, such as the FAA, must prioritize the early creation of regulations and standards. Internationally, agencies and entities like the U.S. Trade Representative and Department of Commerce must similarly prioritize market access for products and services derived from emerging technologies.

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49 Stuart Anderson, "Most Billion Dollar Startups in the U.S. Founded by Immigrants," *Forbes*, July 26, 2022, https://www.forbes.com/sites/stuartanderson/2018/10/25/55-of-americas-billion-dollar-startups-have-immigrant-founder/?sh=5ef62e9e48ee.

50 Anderson, "Most Billion Dollar Startups."

To support orders for new vendors and emerging capabilities, the DoD could consider a special defense working capital fund to facilitate rapid contracts that the armed forces could then repay with follow-on appropriated funds.[51] Such a fund would complement the existing $300 million appropriated for the Accelerating the Production and Fielding of Innovative Technologies (APFIT) program to bridge the valley of death for new technologies,[52] as well as the much smaller $15 million annual appropriation for the National Security and Innovation Capital program (NSIC).[53]

Demonstrate Technology Maturity

NSIC shows how impactful even limited amounts of government capital can be to demonstrate technology maturity. One example is Anthro Energy, which develops batteries based on proprietary polymer technologies developed at Stanford University. The battery technology is not flammable and can yield flexible and conformal batteries. When NSIC made its initial grant to the company in 2022, there were no venture capital investors. With NSIC's support, the company successfully raised its Series A financing in early 2024.[54,55]

Another illustrative example of NSIC's impact is Maybell, the only U.S. company with a quantum computing-enabling dilution refrigerator—critical equipment for any cryogenic quantum development. After completing technology demonstrations through an NSIC grant, Maybell also successfully raised its Series A $25M in venture financing.[56] Given a successful Series A financing round, with continued execution, venture capitalists will likely fund the remaining development.

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51 Cameron Keys and Brendan McGarry, "Defense Primer—Defense Working Capital Funds," Congressional Research Service, February 28, 2024, https://sgp.fas.org/crs/natsec/IF11233.pdf.

52 U.S. Department of Defense, "DOD Announces Next Round of Projects to Receive Funding From Pilot Program to Accelerate the Procurement and Fielding of Innovative Technologies (APFIT)," press release, April 17, 2024, https://www.defense.gov/News/Releases/Release/Article/3745188/dod-announces-next-round-of-projects-to-receive-funding-from-pilot-program-to-a/.

53 Several years prior to the creation of the OSC, the authors advocated for the creation of National Security Innovation Capital (NSIC) with the aim of providing capital to de-risk hardware investments for technologies important to national security like new battery chemistries and quantum sensors. NSIC was authorized in the National Defense Authorization Act of 2018 and placed within the Defense Innovation Unit. While authorized at $75 million per year, Congress only appropriated $15 million per year for this effort; the track record is modest but several dozen companies have now received funds, improved their technology maturity and, as a result, have attracted private VC funding.

54 James Chen, "What is Series A Financing? Process, Definition and Example," Investopedia, April 6, 2022, https://www.investopedia.com/terms/s/seriesa.asp. Series A financing refers to an investment in a privately-held start-up company after it has shown progress in building its business model and demonstrates the potential to grow and generate revenue. It often refers to the first round of venture money a firm raises after seed and angel investors.

55 Michelle Ma, "A Startup's Technology Takes Aim at Lithium-Ion Batteries' Fire Problem," *Bloomberg*, February 29, 2024, https://www.bloomberg.com/news/articles/2024-02-29/san-jose-based-battery-startup-wants-to-fix-lithium-ion-fire-risk.

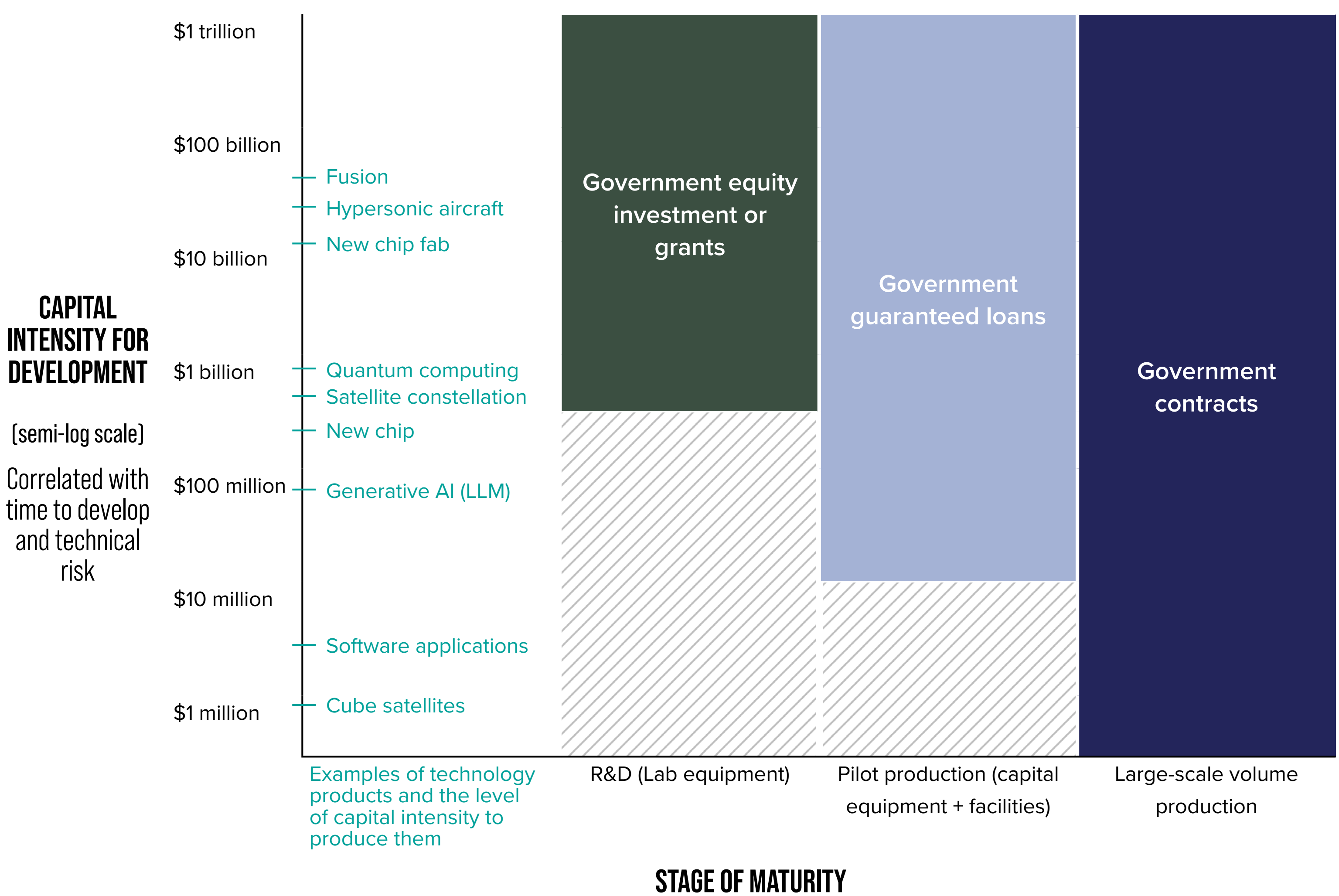
56 Maybell Quantum, "Maybell Quantum Announces $25M Series A Funding LED by Cerberus," press release, March 4, 2024, https://www.maybellquantum.com/articles/maybell-quantum-announces-25m-series-a-funding-led-by-cerberus.

In sum, NSIC grants are specifically designed to demonstrate technology maturity—funding an upcoming development milestone that reduces risk for follow-on private investors. In contrast, the SBIR program (which is today 200 times larger) provides grant awards to fund research that may not be correlated with a technology's level of maturity. As mentioned previously, experienced investors know that SBIR awards historically have a 1 percent transition rate to production defense programs and do not demonstrate any commitment from the U.S. government to future purchases of a solution.

Develop a Public Capital Framework

In considering when to make government capital available, we suggest a framework based on capital intensity and product maturity (Figure 3) guiding where government incentives will be most effective to motivate venture capitalists to invest in hardware or capital-intensive businesses.

Figure 3. Where Government Capital Incentives Will Be Most Effective



First and foremost, a growing and consistent set of orders would have the most impact to motivate venture capitalists as evidence of TAM. Venture capital does not need government incentives to develop even the most complex software, including the large language models (LLMs) of generative AI, which can cost $100 million to develop. Government-provided capital for hardware, however, would be beneficial for technology development but should be variable in size, with larger incentives for higher capital intensity. Capital intensity is correlated both with the technical risk and time required for product development. For software, this time required can be months; for aircraft, it can be a decade or more. Development costs for large-scale hardware can rapidly exceed an individual venture firm's capacity to fund; designing a new chip costs $250 million, but designing and building a chip fab costs $20 billion. Meanwhile, developing hypersonic aircraft or demonstrating the technical feasibility of fusion requires tens of billions of dollars.

In addition to capital intensity, government incentives should vary by capital type, depending on product maturity: equity investments for less mature and more expensive to develop technologies, guaranteed loans for initiating pilot production, and contracts and purchase orders—regardless of capital intensity. For hardware products with development costs less than $500 million, venture capitalists do not need direct government incentives for development or pilot production but will readily invest if there are government contract awards to substantiate demand. For instance, for space-based technologies where there are relatively fewer commercial applications relative to government uses, from new satellites ($1 million to develop) to satellite constellations ($300 million to develop), government purchase orders would prove the TAM and speed the development and deployment of satellites. Where DoD is a large customer and can be a first mover—such as in commercial space, autonomy and energy—government orders are the best approach to stimulate new entrants and ensure a healthy supplier ecosystem. The recent announcement by the U.S. Space Force Satellite Communications Office (SATCOM) to buy $1.7 billion of commercial satellite services in the coming year serves as an example.[57]

However, where R&D development costs of hardware products approach $1 billion or more, accompanied by high capital costs and decades-long development time, government assistance is needed to spur the development itself, not simply to scale production. In the case of fusion and quantum computing, for example, government assistance should be offered in exchange for equity so that the taxpayer dollars invested have the opportunity for the same outsize returns as venture capital. Another example that could benefit from an equity investment is hypersonic aircraft, which require $20 billion for development and testing of a new airframe.

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57 Sandra Erwin, "DoD Forecasts About $1.7 Billion in Commercial SATCOM Buys Over the Coming Year," Space News, May 22, 2024, https://spacenews.com/dod-forecasts-about-1-7-billion-in-commercial-satcom-buys-over-the-coming-year/.

Both these types of government investment—equity and guaranteed loans—enable the government to be repaid and to reallocate the returned capital to fund future hardware investments. With an equity investment, there is the possibility the company will pay back the government at a multiple of the investment cost; similarly, with a loan, there is the possibility the target company will pay back the loan principal with interest.[58] For guaranteed loans, the government should defer the interest until there is a liquidity event for the company. To make loans palatable to equity investors, these loans could be forgiven if there is no future liquidity event or the business fails.[59] With this recommended framework, the incentive type corresponds to risk at each stage of development.

As noted near the outset of this paper, Appendix A provides three case studies for technologies of national interest—quantum, synthetic biology and energy—which struggle for private capital. In all cases, the lack of demonstrated technology maturity is a root cause. For synthetic biology and energy, the lack of capital to scale supporting infrastructure is also a constraining factor.

Conclusion

The geopolitical, economic, environmental, and public health challenges facing the United States are more acute now than at any time since World War II. U.S. policymakers recognize that dual-use technologies are essential to solve these challenges. Venture capital is now the principal engine driving the commercial technology ecosystem, providing the necessary capital and personal networks to translate promising technologies into viable businesses. Thus, venture capital is a critical element to any U.S. industrial strategy centered on technology.

However, venture capitalists optimize their investments for outsized returns and are unlikely to invest in technology that requires significant de-risking, has an uncertain or unformed market, or lacks a capable team. To remain competitive and lead in technologies beyond software where venture funding is more scarce, such as novel energy solutions, quantum information systems, microelectronics, and synthetic biology, U.S. policymakers must prioritize the technologies of highest national interest. Once prioritized, the government should align programs to assist in forming founding teams, coordinate efforts to create markets and signal demand by making the federal TAM visible, and reduce technology risk. However, of all the programs the government can put in place to stimulate venture investment, none is more powerful than issuing contracts and orders to signal demand.

58 The IQT model shows that with sufficient diversification, equity investments can pay back over time, as demonstrated by its investment in Palantir.

59 Loans are superior to equity in capitalization tables, meaning that loans must be repaid before any returns are provided to equity investors. Since these loans are serving a strategic and policy purpose, not just a financial purpose, the U.S. government can forgive the debt rather than forcing a company into bankruptcy to repay debt.

Where hardware development costs are upwards of billions of dollars, government capital can speed development and demonstrate technology maturity faster. However, for less expensive hardware technologies, even a modest grant, like those from the NSIC program, demonstrates that more mature technology will attract venture capitalists. By providing the right incentives to attract venture capital in developing the highest priority technologies for national security, the United States can activate investor appetite, leverage hundreds of billions of dollars in private capital, and better realize future disruptive capabilities. With appropriate incentives, the venture capital industry will finance and support developing the national capabilities needed for economic prosperity and global security.

APPENDIX A: FUNDING PATTERNS IN U.S. STARTUP ECOSYSTEMS OF QUANTUM, BIOTECHNOLOGY, AND ENERGY

Where U.S. policymakers have identified a set of critical technologies essential for national security and economic competitiveness, there are mixed results. Many of these technologies are deep technologies, which are hardware-intensive and capital-intensive. Deep technologies are further described as groundbreaking scientific and engineering innovations requiring substantial investment needed for research, development, equipment, and facilities to demonstrate technology maturity. Primarily due to the lack of demonstrated technology maturity and unformed markets, entrepreneurs in these fields encounter funding hurdles due to the uncertain timeline for commercialization. As a result, entrepreneurs in the United States are either deterred from forming the company in the first place, or they run out of capital in the pre-revenue generating stages of the company's life.

The primary challenge, however, is not a shortage of investment capital available in the private or public sectors. In fact, funding for software technology companies in critical areas is at an all-time high and reflects the continued increased venture capital support for software. (As this paper states, software should not be the focus of government investment.) As Figure A shows, funding for artificial intelligence and machine learning companies alone makes up nearly 25 percent of overall venture funding over the last decade, and in 2024, nearly 44 percent of overall venture investments.

Figure A. U.S. Venture Capital Funding in U.S. Artificial Intelligence (AI) and Machine Learning (ML) Companies, 2015 to 2024 (funding in billions of dollars)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Category totals
AI & ML	$9.85	$16.68	$12.97	$23.20	$31.36	$37.20	$80.29	$55.72	$55.86	$62.51	$385.64
Overall VC funding in United States	**$88.28**	**$85.36**	**$92.15**	**$150.48**	**$154.63**	**$178.22**	**$354.13**	**$245.79**	**$162.72**	**$143.27**	**$1,655.03**
AI & ML investment as a share of overall VC investment	**11%**	**20%**	**14%**	**15%**	**20%**	**21%**	**23%**	**23%**	**34%**	**44%**	**23.3%**

Pitchbook data accessed on September 20, 2024. Graph reflects all VC Stages; U.S. companies; January 1, 2015 to September 15, 2024.

In contrast, the case studies below delve into the current funding dynamics of the U.S. startup ecosystem in the deep tech segments of the three critical technology areas: quantum, biotechnology, and energy.

Quantum

Quantum Information Sciences (QIS) is a central focus for technological innovation across various economic sectors, including materials science, pharmaceuticals, finance, and energy. QIS encompasses a diverse range of segments, each at varying stages of maturity. Quantum sensing and metrology are among the more advanced areas, with applications that include highly sensitive detection of physical quantities such as magnetic fields, time, and gravitational forces. These technologies are already finding use in industries like navigation, defense, and healthcare. Quantum communications, focused on secure data transmission through quantum key distribution (QKD), is also maturing, with several successful demonstrations and early-stage commercial deployments.

Quantum computing, a key component of QIS, promises to revolutionize many industries by solving problems that are too complex for classical computers. However, quantum computing still faces significant technical challenges. In addition to the need for fault-tolerant qubits, other hurdles include maintaining quantum coherence over longer periods and scaling quantum systems to a useful number of qubits.[60] These challenges must be addressed before quantum computing can surpass the capabilities of classical computing, which, given the small size of quantum computers, still manages to achieve everything that classical computers can, albeit less efficiently in certain scenarios.

The strategic advantage of leading in quantum technology is profound, both commercially and militarily. Both the Biden and Trump administrations, along with the U.S. Congress, emphasized that maintaining leadership in QIS is essential not only for economic competitiveness but also for protecting national security and preventing vulnerabilities to adversarial exploitation of quantum technologies.[61] Military and intelligence officials are planning for quantum computing use cases in cryptography, secure communications, advanced simulations, optimization of

60 Edd Gent, "Quantum Computing's Hard, Cold Reality Check: Hype Is Everywhere, Skeptics Say, and Practical Applications Are Still Far Away," IEEE Spectrum, December 22, 2023, https://spectrum.ieee.org/quantum-computing-skeptics.

61 Joseph R. Biden, Jr. "National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems," The White House, May 4, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/04/national-security-memorandum-on-promoting-united-states-leadership-in-quantum-computing-while-mitigating-risks-to-vulnerable-cryptographic-systems/; Executive Office of the President, Office of Science and Technology Policy, "Advancing America's Global Leadership in Science & Technology: Trump Administration Highlights: 2017–2020," October 2020, accessed August 2024, https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/10/Trump-Administration-ST-Highlights-2017-2020.pdf.

military logistics, and enhanced detection technologies, potentially providing significant strategic and tactical advantages.[62]

The combination of the high risk and strategic importance of the technology makes it a perfect candidate for a deepened public-private partnership to ensure enduring competitiveness in the United States. The current health of the U.S. quantum industrial base, specifically in the venture-backed innovation ecosystem, is mixed. In the most generous terms, the size of the domestic startup quantum industrial base over the past decade is roughly 209 companies. These span software and hardware companies, component developers, and quantum algorithm developers, as well as the various modalities of computing, sensing and cryptographic companies.[63]

The bulk of initial funding in the U.S. quantum ecosystem went towards hardware-based elements of the ecosystem. Quantum computing companies, in particular, received a disproportionate amount of the funding from 2015 to 2022. This has been attributed to favorable macroeconomic conditions and the positive hype surrounding the first-of-a-kind nature associated with quantum computing.[64] From a funding perspective, quantum hardware requires highly specialized materials, extreme operating conditions (such as near-absolute zero temperatures), and cutting-edge fabrication techniques, leading to exceptionally high capital expenditures. However, unlike biotech or energy, where the commercial pathway may involve more incremental improvements, quantum computing hardware has the potential for a "winner-takes-all" outcome. This means that investors are often willing to take on higher risks for the possibility of outsized returns if a particular quantum technology achieves scalable success.

As Figure A illustrates, U.S. quantum computing companies received significant funding from 2020 to 2022, reaching $1.2 billion in 2022 and representing 24 percent of total funding in QIS over the previous decade. While this is a positive signal, two factors bear mentioning that should keep policymakers and entrepreneurs vigilant in this space. The first is that despite record funding levels for computing and other hardware components such as semiconductors necessary to enable quantum activities, in aggregate, this funding only represents less than one percent of overall venture funding. Further, in 2023 and 2024, funding has fallen off dramatically, while the capital needs for the quantum companies are still growing. In order to

62 "Summary of NATO's Quantum Technologies Strategy," NATO, January 16, 2024, www.nato.int/cps/en/natohq/official_texts_221777.htm; Kelley M. Sayler, "Defense Primer: Quantum Technology," Congressional Research Service, May 24, 2021, updated August 14, 2024, https://crsreports.congress.gov/product/pdf/IF/IF11836.

63 Data on the U.S. quantum startup ecosystem in the United States were obtained from PitchBook Data, Inc., as accessed on September 15, 2024. PitchBook Data, Inc. is a comprehensive source for private and public market data, including startup funding, valuations, and industry trends.

64 First-of-a-kind technology, and in this case, quantum technology, refers to a breakthrough innovation that achieves a critical proof-of-concept or market entry, representing a high-risk, high-reward opportunity for venture capital investment in uncharted but potentially transformative markets.

bridge this gap, several quantum computing companies raised money through a reverse merger with a Special Purpose Acquisition Company (SPAC). At the time, SPACs offered a faster and often less scrutinized pathway to public markets compared to traditional Initial Public Offerings (IPOs).[65] For quantum computing companies, the immediate access to public market capital was appealing. This route allowed them to bypass the rigorous due diligence of a traditional IPO or the extended timeline required to close a large venture capital round. Given the excitement around quantum computing and its potential to revolutionize industries, these companies were able to secure high valuations and raise significant funds–in one case, $636 million[66]–quickly through SPAC mergers.

Figure B. U.S. Venture Capital Funding in U.S. Quantum Information Systems Technology, 2015 to 2024 (funding in billions of dollars)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Category totals
Quantum Semiconductors	$0.04	$0.02	$0.10	$0.01	$0.03	$0.12	$0.04	$0.04	$0.03	$0.31	$0.74
Quantum Computer Hardware	$0.03	$0.13	$0.16	$0.13	$0.05	$0.32	$0.58	$0.16	$0.08	$0.12	$1.75
Quantum Software	$0.00	$0.00	$0.04	$0.03	$0.04	$0.08	$0.10	$0.67	$0.10	$0.08	$1.14
Quantum Communications and Networking	$0.00	$0.00	$0.00	$0.00	$0.02	$0.01	$0.02	$0.03	$0.01	$0.01	$0.08
Quantum Pharmaceuticals and Biotechnology	$0.00	$0.03	$0.00	$0.00	$0.02	$0.10	$0.08	$0.01	$0.15	$0.10	$0.48
Quantum - Other*	$0.06	$0.13	$0.01	$0.03	$0.01	$0.01	$0.03	$0.26	$0.02	$0.03	$0.59
Total VC Investment in U.S. Quantum Ecosystem	**$0.14**	**$0.31**	**$0.31**	**$0.19**	**$0.16**	**$0.63**	**$0.85**	**$1.16**	**$0.39**	**$0.64**	**$4.79**
Overall VC Funding in United States	**$88.28**	**$85.36**	**$92.15**	**$150.48**	**$154.63**	**$178.22**	**$354.13**	**$245.79**	**$162.72**	**$143.27**	**$1,655.03**
Quantum Investment as a Share of Overall VC Investment	**0.15%**	**0.37%**	**0.34%**	**0.13%**	**0.11%**	**0.36%**	**0.24%**	**0.47%**	**0.24%**	**0.45%**	**0.29%**

Pitchbook data accessed on September 20, 2024. Graph reflects all VC Stages; U.S. companies; January 1, 2015 to September 15, 2024.
*Other includes fields such as transportation, energy, materials and can include overlaps with the primary sectors listed here.

However, some of the quantum companies that pursued a SPAC are now trading at substantial discounts and under threat of being delisted from the major stock exchanges.[67] The decline in their market capitalizations can be attributed to several factors. The speculative nature of quantum computing, with commercial viability still years away, has led to investor skepticism.

65 U.S. Securities and Exchange Commission, "Types of Registered Offerings," last updated September 19, 2024, https://www.sec.gov/resources-small-businesses/capital-raising-building-blocks/types-registered-offerings.

66 IonQ, "IonQ Becomes First Publicly Traded, Pure-Play Quantum Computing Company; Closes Business Combination with dMY Technology Group III," press release, October 1, 2021, https://ionq.com/news/october-01-2021-ionq-listed-on-nyse.

67 John Russell, "Quantum Pioneer D-Wave Again Faces NYSE Delisting," *HPCwire*, October 24, 2023, https://www.hpcwire.com/2023/10/24/quantum-pioneer-d-wave-again-faces-nyse-delisting/.

The initial excitement surrounding quantum technology has not yet translated into immediate, scalable, and profitable applications. Additionally, the broader market sentiment has shifted, with investors becoming more cautious and favoring companies with clearer paths to profitability, especially in the context of rising interest rates and a more risk-averse environment.

The most acute concern regarding the collapse of these companies is the potential loss of existing capability they are providing to the national security community. Additionally, with persistently low stock prices and the need for additional capital, the publicly listed quantum computing companies could become vulnerable to acquisition or closure, which introduce other concerning implications. These include the loss of specialized talent and a broader decline in investor interest due to the perceived failure of industry leaders to deliver breakthroughs. Additionally, the collapse of key players could expose supply chain vulnerabilities, particularly for smaller specialized suppliers, and create opportunities for foreign entities to acquire valuable intellectual property that currently resides with these companies.

To avoid this fate, the government could make this technology more attractive for venture capital by investing government capital to demonstrate technology maturity. With improved technology maturity, private capital would invest and commercialize this technology more rapidly.

Biotechnology

Biotechnology is a diverse and rapidly advancing field, encompassing sectors at various stages of technological and commercial maturity. Biopharmaceuticals, one of the more established areas, includes the development of biologics such as monoclonal antibodies, gene therapies, and cell therapies, which are transforming treatments in oncology, immunology, and genetic disorders. These innovations have already led to marketable products and a robust clinical pipeline, demonstrating the sector's commercial viability. In contrast, synthetic biology, while still in its nascent stage, holds immense potential to transform industries like agriculture, chemicals, and manufacturing by enabling the sustainable production of biofuels, chemicals, and food. However, challenges related to scalability, biosafety, and regulatory hurdles remain significant obstacles to widespread adoption.

The strategic importance of achieving competitiveness in biotechnology has garnered significant attention from both the White House and Congress due to its national security and economic implications. The White House, through Executive Order 14081 and the subsequent National Biotechnology and Biomanufacturing Initiative,[68,69] emphasizes the role of biotechnology in addressing critical societal goals such as climate change, food security, and supply chain resilience, while also underscoring its potential to drive the U.S. bioeconomy and create domestic jobs. Simultaneously, Congress, through the National Security Commission on Emerging Biotechnology,[70] highlights biotechnology as a key factor in future defense capabilities, focusing on the need for the United States to secure global leadership in biotechnology to maintain a technological advantage in national security. Both the Administration and Congress recognize that public-private partnerships and significant R&D investments are necessary to harness biotechnology for national and economic security.

The biotechnology industry can be segmented based on its hardware and software needs. Hardware-intensive sectors, such as cell and tissue engineering, industrial biotechnology, and synthetic genomics, require significant investments in specialized equipment like bioreactors and fermentation tanks to enable large-scale biological production. These sectors require significant capital, especially in scaling infrastructure. On the other hand, software-based segments, including biocomputing and synthetic biology platforms, focus on data analysis and computational tools that support research and development without the need for heavy infrastructure. By leveraging AI, machine learning, and automation, these software-driven fields streamline processes like genetic editing and drug discovery, enabling advancements with lower capital intensity than their hardware counterparts.

Current Funding Dynamics for Biotechnology in the U.S. Venture Ecosystem

As Figure B demonstrates, funding at the aggregate for biotechnology is healthy; at $250 billion over the past decade, it has averaged roughly 15 percent of overall VC funding in the United States during the same period. The disproportionate funding within the category goes to biopharmaceuticals due to their high revenue potential, strong market demand, and robust exit opportunities, despite inherent risks. The combination of unmet medical needs, platform technologies, and favorable regulatory support makes them especially appealing to

68 The White House, "Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy," September 12, 2022, https://www.whitehouse.gov/briefing-room/presidential-actions/2022/09/12/executive-order-on-advancing-biotechnology-and-biomanufacturing-innovation-for-a-sustainable-safe-and-secure-american-bioeconomy/.

69 The White House: "FACT SHEET: The United States Announces New Investments and Resources to Advance President Biden's National Biotechnology and Biomanufacturing Initiative," September 14, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/14/fact-sheet-the-united-states-announces-new-investments-and-resources-to-advance-president-bidens-national-biotechnology-and-biomanufacturing-initiative/.

70 Congressionally Chartered National Security Commission on Emerging Biotechnology, National Defense Authorization Act for Fiscal Year 2022, 117th Congress, §1091, 135 Stat. 1541, December 27, 2021.

venture capital investors. Biopharmaceuticals are followed by startups in the medical device sector (MedTech). MedTech encompasses innovations in medical devices, diagnostics, and digital health solutions. Wearable health monitors, popularized in fitness startups, leverage AI-driven diagnostics and drove a wave of venture investment seeking to capture vast market opportunities. Additionally, MedTech generally has shorter development cycles and lower regulatory hurdles compared to drug development, enabling investors to achieve faster returns on investment.

Figure C. U.S. Venture Capital Funding in U.S. Biotech, 2015 to 2024 (funding in billions of dollars)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Category totals
Industrial Biotechnology	$0.02	$0.03	$0.09	$0.07	$0.04	$0.15	$0.13	$0.15	$0.12	$0.12	$0.92
Biopharmaceuticals	$7.09	$6.05	$8.50	$12.60	$11.17	$16.79	$23.53	$15.76	$13.04	$11.86	$126.39
Synthetic Biotechnology	$0.24	$0.06	$0.15	$0.65	$0.37	$0.74	$1.31	$1.35	$0.72	$0.35	$5.94
Genetic Engineering	$0.98	$0.84	$0.91	$1.82	$1.94	$3.74	$6.73	$3.26	$3.72	$1.46	$25.40
Bioinformatics	$1.87	$1.35	$2.84	$2.67	$2.24	$3.61	$5.06	$4.21	$1.97	$2.45	$28.27
Agricultural biotech	$0.48	$0.23	$0.86	$0.48	$0.62	$0.67	$1.53	$1.35	$0.93	$0.70	$7.85
Biocomputing platform	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Cell and Tissue Engineering	$0.01	$0.01	$0.02	$0.00	$0.02	$0.03	$0.03	$0.13	$0.01	$0.06	$0.32
Medtech	$1.73	$2.27	$2.26	$5.06	$4.34	$7.44	$10.31	$10.05	$4.19	$4.40	$52.05
Total VC Investment in U.S. Biotech, by year	$12.42	$10.84	$15.63	$23.35	$20.74	$33.17	$48.63	$36.26	$24.70	$21.40	$247.14
Overall VC Funding in United States	$88.28	$85.36	$92.15	$150.48	$154.63	$178.22	$354.13	$245.79	$162.72	$143.27	$1,655.03
Biotech Investment as a Share of Overall VC Investment	14%	13%	17%	16%	13%	19%	14%	15%	15%	15%	14.93%

Pitchbook data accessed on September 20, 2024. Graph reflects all VC Stages; U.S. companies; January 1, 2015 to September 15, 2024.
*Other Biotechnology categories exist in Pitchbook, this represents a majority of the relevant categories for this inquiry.

Areas such as synthetic biology and genetic engineering, which are stated national priorities,[71] represent roughly 12 percent of overall biotech funding. Some startup companies receiving funding offer products and services leveraging CRISPR and gene editing technologies; others are modifying or creating new organisms, such as bio-manufacturing and engineered microbes

71 Fast Track Action Subcommittee on Critical and Emerging Technologies, National Science and Technology Council, "2022 Critical and Emerging Technologies List Update," OSTP, Executive Office of the President, February 2022, https://www.whitehouse.gov/wp-content/uploads/2022/02/02-2022-Critical-and-Emerging-Technologies-List-Update.pdf; The White House, "Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy," September 12, 2022, https://www.whitehouse.gov/briefing-room/presidential-actions/2022/09/12/executive-order-on-advancing-biotechnology-and-biomanufacturing-innovation-for-a-sustainable-safe-and-secure-american-bioeconomy/.

for industrial uses. These innovations can be applied across healthcare, agriculture, and industrial biotechnology. Critically, as the U.S. government contemplates various restrictions on engagement with China-based companies, particularly Contract Research Organizations (CRO) such as WuXi AppTec, there will likely be second order effects on the funding going to U.S. startups.[72] Currently, these CROs enable small biotech companies to avoid massive capital expenditures for manufacturing and testing equipment while accelerating R&D and commercialization efforts. This allows entrepreneurs to demonstrate rapid progress on milestones to investors and raise additional funding. Without viable, cost-competitive CRO alternatives, these areas could see investment decrease in the coming years.

In biotechnology sectors that currently lack sufficient private capital, the challenges stem from both technological immaturity and insufficient industrial infrastructure to scale production and manufacturing. To unlock the potential of these areas, the U.S. government can leverage the capital framework discussed in this report, deploying non-dilutive funding, such as substantial loans or grants, in collaboration with private investors. This approach would help finance critical infrastructure while incentivizing private investment to advance technology maturation and readiness for commercialization.

Energy

The energy sector is similarly diverse and rapidly evolving, with a range of component technologies at various stages of development and commercialization. Clean energy, including renewables like solar, wind, hydro, geothermal, nuclear, biofuels, and emerging fusion technologies, is transforming the global power landscape by providing sustainable alternatives to fossil fuels. Energy storage and grid modernization, through advancements in battery technologies and infrastructure, are critical to stabilizing energy systems and ensuring the efficient distribution of renewable power. Electrification technologies, including electric vehicles (EVs), EV infrastructure, and critical minerals, are gaining momentum as countries aim to reduce emissions from transportation, while carbon capture technologies are essential to mitigating greenhouse gas emissions from industrial sources and achieving net-zero goals.

Countries around the world are intensely focused on achieving leadership in these fields, recognizing their strategic importance to economic growth and energy independence. For example, Japan has made significant advances in hydrogen energy technology, positioning itself as a leader in developing a hydrogen-based economy.[73] Japan has implemented large-scale initiatives to integrate hydrogen into its energy mix, with investments in hydrogen

72 Christina Jewett, "Chinese Company Under Congressional Scrutiny Makes Key U.S. Drugs," *The New York Times*, April 15, 2024, https://www.nytimes.com/2024/04/15/health/wuxi-us-drugs-congress.html.

73 Naoko Tochibayashi and Naoko Kutty, "Hydrogen Is Developing Fast in Japan, Edging Nearer to Wider Use in Society," World Economic Forum, April 10, 2024, www.weforum.org/agenda/2024/04/hydrogen-japan.

fuel cells, storage, and transportation infrastructure that aim to decarbonize sectors like transportation and heavy industry. Similarly, the European Union has emerged as a global leader in offshore wind energy, particularly with countries like Denmark and Germany at the forefront of deploying large-scale wind farms,[74] which are critical to meeting the EU's ambitious renewable energy targets.

The energy industry can be segmented based on its hardware and software needs. Hardware-intensive sectors include clean energy technologies like solar, wind, hydro, geothermal, nuclear, and biofuels, which require substantial investments in physical infrastructure such as power plants, wind turbines, solar farms, and advanced reactors. Emerging areas like fusion energy are especially capital-intensive due to the need for cutting-edge facilities and equipment for research and development. Energy storage and grid modernization also involve significant hardware components, such as large-scale battery installations and grid infrastructure, to manage energy distribution efficiently. However, grid modernization is a hybrid sector, with substantial software needs to optimize energy flows through smart grids and advanced control systems, alongside the physical infrastructure. In EV and electrification, hardware demands are high for electric vehicle production, battery manufacturing, and EV charging infrastructure, but software plays a critical role in managing charging networks, optimizing battery performance, and integrating electric vehicles into the grid. Conversely, software-driven segments in the energy ecosystem, such as energy management systems, rely heavily on computational tools like AI, machine learning, and predictive analytics to optimize energy use and monitor grid health, often with lower capital intensity compared to hardware-focused sectors. Carbon capture technologies, though still capital-intensive due to the need for specialized facilities, are increasingly integrating software solutions to enhance capture efficiency and monitor emissions in real-time.

Current Funding Dynamics for Energy in the U.S. Venture Ecosystem

The startup ecosystem in novel energy technologies has experienced booms and busts over the past two decades. Spurred by strong political signals in the Obama Administration, clean energy technology generated significant enthusiasm amongst venture capitalists, with some prominent firms re-orienting much of their capital towards the potential business opportunities.[75] While investor sentiment ultimately cooled in the early part of the 2010s, at the start of the 2020s, the sector is once again generating interest. However, as Figure C shows, investors

74 "Denmark Launches Its Biggest Offshore Wind Farm Tender," *Reuters*, April 22, 2024, https://www.reuters.com/sustainability/climate-energy/denmark-launches-its-biggest-offshore-wind-tender-2024-04-22/.

75 Sarah McBride and Nichola Groom, "How cleantech tarnished Kleiner and VC star John Doerr," *Reuters*, January 16, 2013, https://www.reuters.com/article/world/how-cleantech-tarnished-kleiner-and-vc-star-john-doerr-idUSBRE90F0AE/.

are making cautious bets; overall investment into novel energy technology modestly averages about 6 percent of overall venture investment over the previous decade. 2021 and 2022 were high watermark years, tracking the increase in overall VC investment and no doubt buoyed by the U.S. government's passage and early implementation of the Inflation Reduction Act (IRA) and Infrastructure Act. Market signaling has been quite strong for electric vehicles, and this has transmitted to the venture ecosystem; electric vehicles lead the way in funding, with nearly $28 billion in investment over the past decade, followed closely by energy storage technologies and nuclear energy. While funding in clean and alternative energy has been relatively small, investors are closely monitoring the surging energy demands for artificial intelligence companies and are exploring how to place bets on clean energy solutions.[76]

Figure D. U.S. Venture Capital Funding in U.S. Energy Ecosystem, 2015 to 2024 (funding in billions of dollars)

	Categories	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Totals
Clean & Alternative Energy	Renewable Energy	$0.29	$0.29	$0.25	$0.40	$0.18	$1.29	$2.49	$0.61	$2.26	$0.31	$8.37
	Hydropower	$0.04	$0.01	$0.05	$0.04	$0.02	$0.08	$0.21	$0.00	$0.09	$0.03	$0.57
	Geothermal	$0.15	$0.02	$0.01	$0.06	$0.05	$0.05	$0.24	$0.34	$0.08	$0.38	$1.38
	Nuclear Energy	$1.08	$0.03	$0.60	$0.60	$1.19	$2.99	$3.05	$3.31	$2.42	$0.56	$15.83
	Hydrogen	$0.11	$0.13	$0.16	$0.34	$0.23	$0.63	$1.41	$1.82	$1.73	$0.84	$7.40
	Biofuels	$0.46	$0.11	$0.12	$0.24	$0.10	$0.16	$0.27	$0.73	$0.81	$0.29	$3.29
	Fusion Energy	$0.09	$0.08	$0.21	$0.26	$0.30	$0.13	$2.63	$0.44	$0.16	$0.41	$4.71
Energy Storage/ Grid Modernization	Battery	$0.18	$0.23	$0.21	$0.34	$0.31	$0.40	$0.73	$1.31	$0.44	$0.39	$4.54
	Grid Modernization	$0.00	$0.00	$0.00	$0.00	$0.00	$0.01	$0.00	$0.03	$0.00	$0.00	$0.04
	Energy Storage	$0.66	$0.76	$0.70	$1.29	$1.07	$1.74	$4.95	$4.12	$3.58	$3.60	$22.47
EV and Electrification	Electric Vehicle	$0.29	$1.49	$0.57	$4.19	$3.80	$4.36	$7.50	$3.52	$1.37	$0.91	$28.00
	Critical Minerals	$0.00	$0.00	$0.00	$0.03	$0.00	$0.01	$0.16	$0.01	$0.32	$0.01	$0.54
Carbon Capture	Carbon Capture	$0.36	$0.52	$0.25	$0.72	$0.32	$0.63	$0.82	$2.59	$0.93	$0.65	$7.79
Yearly Totals		$3.71	$3.67	$3.13	$8.51	$7.57	$12.48	$24.46	$18.83	$14.19	$8.38	$104.93
Overall VC Funding in US		$88.28	$85.36	$92.15	$150.48	$154.63	$178.22	$354.13	$245.79	$162.72	$143.27	$1,655.03
Energy Funding as a share of Overall VC Investment in the U.S		4%	4%	3%	6%	5%	7%	7%	8%	9%	6%	6.34%

Pitchbook data accessed on September 20, 2024. Graph reflects all VC Stages; U.S. companies; January 1, 2015 to September 15, 2024.

*Other Energy categories exist in Pitchbook, this represents a majority of the relevant categories for this inquiry

.The legislative intent behind the IRA, CHIPS Act, and Bipartisan Infrastructure Law was to seed U.S. manufacturing in clean energy technologies, but these efforts are now facing headwinds. The Financial Times reports that 40% of major manufacturing projects tied to these laws have

76 Jared Cohen and John Goldstein, "Investing Where AI, Energy and Politics Intersect," Goldman Sachs Asset Management, July 29, 2024, https://am.gs.com/en-us/advisors/insights/article/2024/Investing-where-ai-energy-and-politics-intersect; Dylan Sloan, "OpenAI's Sam Altman Is Funding a Green-Energy Moonshot as AI's Power Demands Grow to 'Insatiable' Levels," *Fortune*, April 22, 2024, https://fortune.com/2024/04/22/sam-altman-ai-energy-power-consumption-startup-renewable-solar/.

been delayed, with $84 billion worth of initiatives announced in the first year experiencing slowdowns.[77] This is particularly affecting venture-backed technology startups in the energy sector, which are increasingly walking away from ambitious projects or returning funds. For instance, Lilac Solutions, a startup "working on a method of rapidly extracting lithium from brine, backed away from a $50 million grant."[78] Broader challenges, such as declining EV sales, competition from cheap imports from China, and potential talent shortages in the U.S., are further complicating efforts to establish a robust industrial base for advanced energy technologies.[79] Policymakers must address these obstacles to ensure the continued growth and competitiveness of the U.S. clean energy economy.

In the energy sector, while government programs exist to fill financing gaps, they often are not sufficient to offset investor risk, particularly for startups requiring significant investments for scaling. Investors are hesitant to fund these ventures, knowing the immense resources required down the road. The Department of Energy (DOE) has created financial mechanisms like the Office of Demonstration, SCALEUP at ARPA-E, and the Loan Program Office (LPO) to help bridge this gap, providing support for technologies in the pilot or demonstration phase. However, for earlier-stage companies, the pace and funding levels from these programs remain too slow and inadequate, making it challenging to secure the capital needed for technology development and ultimately for commercialization.

Conclusion

As illustrated in these case studies, deep technologies of national interest are often constrained by technology maturity and access to capital equipment and infrastructure for scaling. As policymakers evolve the design of government investment programs, it will be important to study the growth profile of companies in the startup ecosystem to understand the needs and incentives of the different stakeholders (i.e. entrepreneurs and investors) at different stages of the company's life cycle. Leveraging a capital framework like the one outlined in this report is one way to ensure that public interventions effectively partner with the critical players in the innovation ecosystem and make the most effective use of taxpayer funds. Without this alignment, the United States risks deploying substantial capital and administrative resources without achieving the intended outcomes of new company formation, resilient supply chains, industry leadership, economic growth, and enhanced capabilities for national security.

77 Amanda Chu, Alexandra White, and Rhea Basarkar, "Delays Hit 40% of Biden's Major IRA Manufacturing Projects," *Financial Times*, August 11, 2024, https://www.ft.com/content/afb729b9-9641-42b2-97ca-93974c461c4c.

78 Steve LeVine, "One in Four Recipients of a U.S. Battery Grant Has Given Them Up," *The Information*, September 12, 2024, https://www.theinformation.com/articles/one-in-four-recipients-of-a-u-s-battery-grant-has-given-them-up.

79 Ali Rogin and Andrew Corkery, "A Look at the Economic Impact and Progress of Biden's Inflation Reduction Act So Far," *PBS NewsHour*, September 21, 2024, https://www.pbs.org/newshour/show/a-look-at-the-economic-impact-and-progress-of-bidens-inflation-reduction-act-so-far.

APPENDIX B: IMPORTANCE OF A DUAL-USE TECHNOLOGY RACE

In a dual-use tech race, technology takes on elevated importance to commercial industry as well as the military. To understand its importance, compare the communications sector's transition from the 3rd generation (3G) to the 4th generation (4G)—a race in which the United States maintained its technology lead—to the subsequent transition to 5G: a race in which China strove to undermine the U.S. lead and threaten the security of global communications. Through its technology leadership, the United States introduced 4G and LTE network services in 2008, featuring data transfer rates of ten times those of 3G by leveraging IP (internet protocol) networks that enabled video and mobile applications. The introduction of 4G contributed to 70 percent revenue growth in the wireless industry from 2011-2014 and increased jobs by more than 80 percent. By leading this race, the United States built a global ecosystem of network providers, device manufacturers, and app developers which, in turn, created an economic boom.[80] Mobile wireless is illustrative of the first-mover advantage, where the first mover enjoys a network effect by setting the foundational infrastructure and specifications for future products.

The 5G transition will further improve network speeds and reduce latency, enabling applications such as autonomous vehicles and other Internet of Things (IoT) capabilities, including AI-powered health care. Huawei, supported as a national champion of the Chinese government with land and capital subsidies, attempted to displace the United States in the transition from 4G, taking an early lead in deployments of 5G base station hardware. In replacing U.S. and European telecommunications infrastructure, Huawei further aimed to use 5G both to benefit economically (as the United States did in the 4G race) and to enable the military to conduct global surveillance, carry out denial-of-service attacks on adversaries, and reduce latencies for military IoT applications like swarming drones.[81] Should Huawei succeed at leading the 5G transition, China would not only be able to spy on global communications, but also would capture tremendous economic benefits by creating a Chinese ecosystem of network providers, device manufacturers, and app developers. The Chinese military would have benefited by having a first-mover advantage with access to new military technologies such as more capable autonomous systems like swarming drones.

80 Milo Medin and Gilman Louie, *The 5G Ecosystem: Risks and Opportunities for DoD* (Arlington, VA: Defense Innovation Board, April 3, 2019), https://media.defense.gov/2019/Apr/03/2002109302/-1/-1/0/DIB_5G_STUDY_04.03.19.PDF.

81 Daniel Araya, "Huawei's 5G Dominance in the Post-American World," *Forbes*, April 5, 2019, https://www.forbes.com/sites/danielaraya/2019/04/05/huaweis-5g-dominance-in-the-post-american-world/.

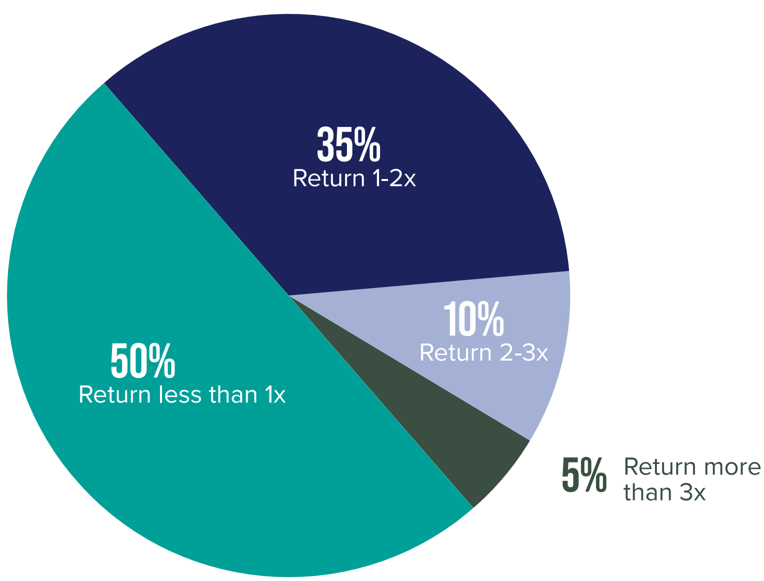
If China succeeds in its plans for industry dominance of critical and emerging technologies, as outlined in Made in China 2025 and China Standards 2035, then it will capture trillions of dollars in economic output, and the United States and its allies will become dependent on China for a host of new technologies critical for economic development and national security such as quantum computing and cryptography, advanced computing, advanced telecommunications, synthetic biology and more. Should it succeed, China's coercive power will grow and the U.S. economy will be limited in its growth potential, with a reduced number of high-paying jobs linked to these new technologies. China will likely leverage such success to overtake the overall U.S. economy in size and to limit it to concentration in sectors such as financial services, agriculture, and low-skill services. If China achieves industry dominance, U.S. military leadership will also decline due to both technological disadvantages and lower affordability.

APPENDIX C: POWER LAW IN PRACTICE

How does the power law work?

If a venture firm invests $100 million in a portfolio of 10 companies, at say $10 million per investment, and yields $400 million from a single investment [40x return on that single investment and >4x the fund's total invested capital (after fees), more than returning the fund], then the firm becomes a top five percent performer in the venture industry, even if the other investments in the VC portfolio all go out of business. Only 5% of VC firms return 3x the capital invested in them, sometimes called "the venture rate of return." This means venture firms do not seek an *average* return for each investment but rather an *outsize* return (say, 20 to 40x) on each investment, since the VC does not know in advance which of its portfolio companies will be a big success. Even with a dismal record of nine losses and one win, the venture firm is highly successful if that single win generates 40 times the returns. That highly successful firm will then have earned a reputation as an astute investor and will be able to attract capital for its next fund and to appeal to aspiring entrepreneurs wishing to leverage its reputation as a smart investor. Figure E shows the skewed distribution of returns for the VC industry and illustrates that only the top 15 percent of firms return 2x or more of an investor's capital, with half of the industry losing money.

Figure E. Distribution of Returns in Venture Capital[82]



82 Andrew Glen, "Navigating VC Challenges in Defense and Hard Tech," Substack, January 10, 2024. https://andrewglenn.substack.com/p/navigating-vc-challenges-in-defense?utm_source=profile&utm_medium=reader2; Marina Temkin, "VCs Hope Plunging IRR Is Behind Them," Pitchbook News and Analysis, October 1, 2023, https://pitchbook.com/news/articles/vc-performance-irr-down-double-digits.

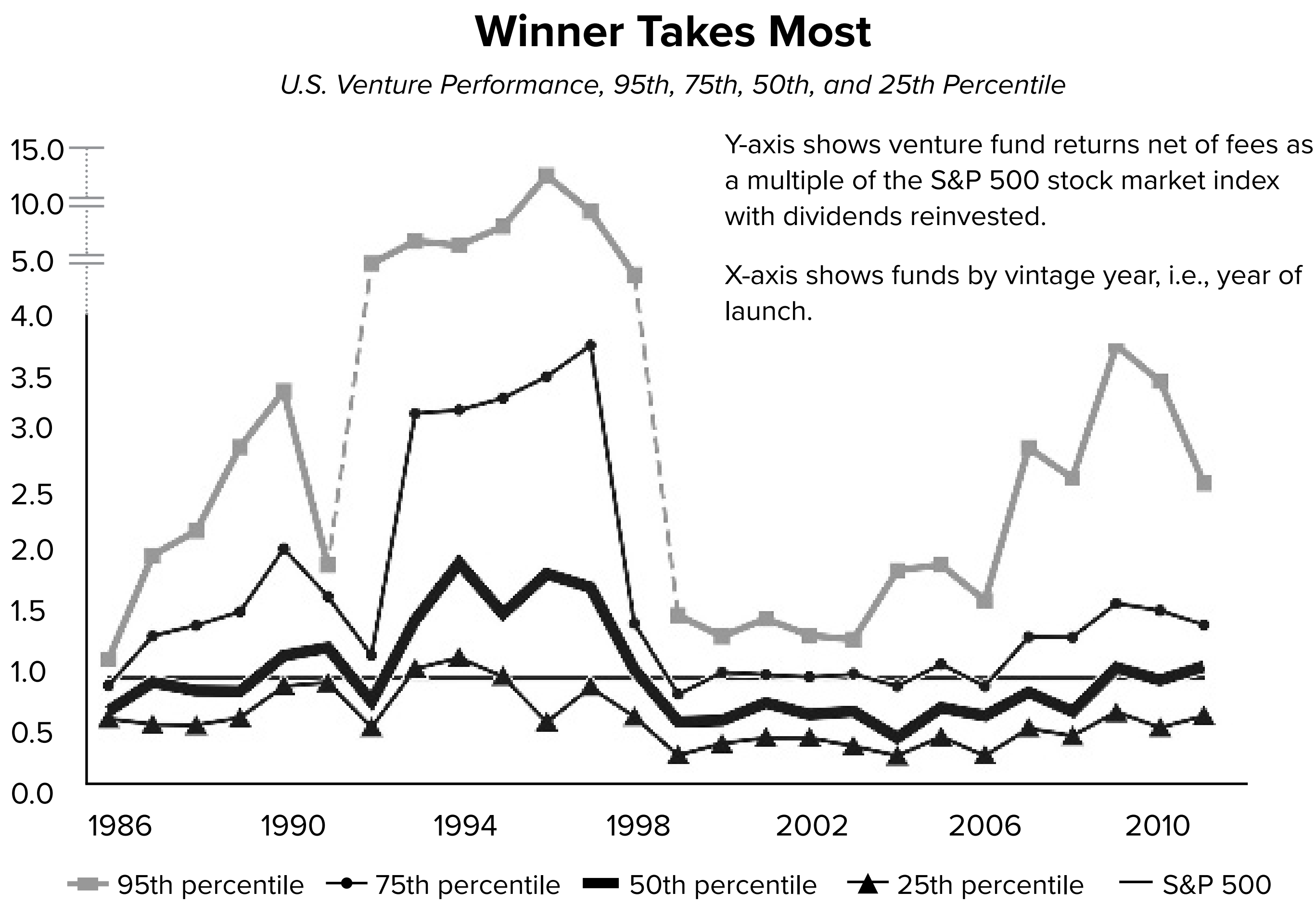
A venture firm is typically compensated with a “2 and 20” fee structure, meaning that the compensation to the venture firm management company (called the “general partner” or GP and exemplified by Sequoia, Kleiner Perkins, and Andreesen Horowitz) will be annual fees of 2 percent of the total fund capital raised to cover salaries and expenses plus 20 percent of the equity value in the fund after returning the investors’ capital.83 This equity upside is called “the carry,” or carried interest of the fund. This carried interest will be split among the members of the GP. Of course, if the fund does not earn more than 1x the capital invested, the carried interest is zero.

In our example above, over the ten-year life of the fund, the GP fees would be $20 million (2 percent of the $100 million in committed capital times 10 years). The value of the invested capital over the ten-year life of the fund in our example is then: $400 million - $20 million in fees = $380 million for distribution to the partnership (made up of GPs and limited partners (LPs), exemplified by institutions like university endowments or pension funds). The payback to the LPs would be the return of their investment capital ($80 million) + 80 percent of the equity upside ($300 million) = $320 million or a net return on invested capital of 3.2x.84 (Note the gross return on invested capital would be inclusive of fees, or the full $400 million. In this example, the gross return on investment is 4x, while the gross return on invested capital would be the return of capital [$100 million inclusive of fees] plus 80% of the equity upside [$300 million] = $340 million or a gross return on invested capital of 3.4x.) For the GP, the fees would be $20 million and the investment return would be 20 percent of the equity upside ($300 million) = $80 million.

83 In some cases, fees are only charged on committed capital rather than total investment capital. For simplicity, this example uses 2% x investment capital ($100 million) times 10 years = $20 million. If fees are calculated on committed capital, fees are 2% x $80 million (invested capital) x 10 years = $16 million. Typically, the GP makes a contribution to the fund to align interests of the management company with the LPs. Sometimes the GP contribution or a portion of the GP contribution funds the 2% management fee.

84 The example uses simplified assumptions and the actual returns calculation would be dependent on the firm’s governing documents. For example, some VC firms calculate the 20 percent upside on a deal-by-deal basis which is favorable to the GP; others on a total basis, meaning the GP must return 100 percent of capital to investors before the upside is calculated.

Figure F. Distribution of Venture Returns Over Time: Skewed to Top Performers



Graph and data from Sebastian Mallaby, *The Power Law: Venture Capital and the Making of the New Future* (Council on Foreign Relations Book, Penguin Press, 2022), appendix.

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