# Critical and Emerging Technologies Index

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# About the Defense, Emerging Technology, and Strategy Program

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# Executive Summary

News headlines often make sweeping claims about the geopolitics of technology today—for instance, suggesting that China has far surpassed the United States in advanced technologies, or that Europe is losing ground in technology competition. Yet it is difficult to find robust, cross-sector data to support such comparisons. The Critical and Emerging Technologies Index helps fill this gap by enabling policymakers, strategists, and researchers to assess the technological power of 25 countries. Built using thousands of public and commercial data points, the Index is a quantitative model presented through an interactive dashboard that benchmarks progress in Artificial Intelligence (AI), Biotechnology, Semiconductors, Space, and Quantum. The dashboard features adjustable indicators within each sector, allowing users to customize the model and gain insights into the relative strengths and shortcomings of each country.

This report provides context and analysis that help make sense of the data visualized in the Index Dashboard. It offers unique insights into the ways in which the geopolitics of technology are changing, both within and across sectors.

**Key Judgments:**

- **The United States leads China and Europe in all sectors of the Index, primarily because of the unique innovation ecosystem that it has developed over the past several decades.** U.S. performance is largely powered by economic resources and human capital, reflected in the scale of American public and private investment and its heterogeneous research workforce. The country's decentralized innovation ecosystem—where resources, ideas, and authority are distributed across a myriad of government entities, universities, start-ups, and corporations—enables actors to expediently pool expertise and scale innovations.

- **Although China still trails the United States, it remains competitive and is closing the gap across several sectors.** China lags in semiconductors and advanced AI due to reliance on foreign equipment, weaker early-stage private research, and shallower capital markets, but it is far closer to the United States in biotechnology and quantum, where its strengths lie in pharmaceutical production, quantum sensing, and quantum communications. Backed by economic resources, human capital, and centralized planning, China is leveraging scale to reduce dependence on imports, attract innovation within its borders, and boost industrial competitiveness.

- **Europe is competitive in critical and emerging technologies relative to the U.S.-China duopoly.** Europe is third in the context of AI, biotechnology, and quantum technologies. Yet China and Russia outpace Europe in space, and China, Japan, Taiwan, and South Korea eclipse Europe in semiconductors. Indeed, Europe's shortcomings with semiconductors significantly lower Europe's overall standing compared to the United States and China. The region's ability to fulfill its technological potential will ultimately depend on the integration of governance and capital across the region.

- **Collaborative partnerships with Europe, Japan, and South Korea make the United States significantly more powerful in critical and emerging technologies, particularly in the context of quantum, semiconductors, and biotechnology.** The United States is powerful across all sectors but does not have full supremacy; for instance, no country has complete, end-to-end control of a supply chain for advanced semiconductors. These gaps create critical chokepoints, limiting the ability of any one country to shape the global balance of power alone. To ensure that the West remains competitive and resilient, the United States must deepen collaboration with its allies and partners.

- **The United States has a considerable advantage in AI, but China and Europe have made significant progress and have unique advantages that will challenge the American AI lead in the next decade.** The United States dominates in terms of its economic resources, computing power, and algorithms. The 2025 release of DeepSeek's R1 model and Alibaba's Qwen3 family of models, however, demonstrated that the U.S. lead in AI may be more vulnerable than previously assumed. China leads in terms of data and human capital; these advantages will help it close the U.S. edge in AI if it can overcome the obstacles presented by U.S. export controls. Europe's strength in AI is largely derived from its strong data and human capital, giving it the potential to accelerate its AI capabilities if it improves its regulatory environment.
- **Among the technologies examined in this Index, China has the most immediate opportunity to overtake the United States in biotechnology; the narrow U.S.-China gap suggests that future developments could quickly shift the global balance of power.** The United States and China perform similarly in biotechnology overall, with China's strengths underpinned by its human capital. The United States excels in security, genetic engineering, vaccine research, and agricultural technology, bolstered by private-sector innovation and public-private partnerships. China has dominance in pharmaceutical production through extensive, large-scale public investments and state-backed manufacturing.
- **The dominance of the United States, Japan, Taiwan, and South Korea in semiconductors persists at critical chokepoints of the supply chain: advanced manufacturing and fabrication, chip design and tools, and equipment.** These pillars have the greatest variance among all included in this Index due to high costs and technical barriers. While many countries are investing heavily to close these gaps, capital alone is unlikely to be sufficient to establish an end-to-end semiconductor production capability; if countries aim to break free from dependence on the current leaders, they will need to simultaneously secure equipment and advance chip design.
- **The American private sector drives the United States' strong lead in space, though its vulnerabilities in orbit to Chinese and Russian military capabilities increase strategic risk.** Washington's edge stems from productive public-private partnerships that have helped the United States dramatically increase its launch frequency and payload capacity while reducing per-mission costs. However, the United States is asymmetrically vulnerable in space, relying heavily on space-based systems for military operations and for supporting critical sectors of the American economy. China and Russia are also fielding formidable anti-satellite capabilities, offsetting the United States' lead in space and increasing its strategic exposure.
- **Quantum technologies remain in an early research phase, with current efforts focused less on deployment and more on advancing early-stage concepts**. This relative lack of investment has contributed to the fragmented and region-specific development of quantum ecosystems. In the United States and Europe, universities lead foundational research, startups develop specialized tools and systems, and large corporations scale engineering and infrastructure for quantum technologies. China takes a more opaque, state-led approach, with less separation between research, development, and industry.

# Introduction

## Power in Numbers

This publication introduces the inaugural Critical and Emerging Technologies Index, designed to help policymakers and strategists assess national power in and across critical domains of technology. Built using public and commercial data, the Index is visualized through an interactive dashboard that benchmarks advancements across 25 countries in Artificial Intelligence (AI), Biotechnology, Semiconductors, Space, and Quantum. The Dashboard features adjustable indicators within each technological sector, empowering users to make custom changes and obtain insights into each country's relative strengths and shortcomings.

Power is difficult to define and measure. While some policymakers see it primarily in terms of military might, others point to economic strength or ideational and cultural influence as more relevant indicators.[1] This report defines power as the ability of a nation to achieve its national interests through the control of resources, material, and ideas.[2] In a world increasingly defined by innovation, critical and emerging technologies are integral to national power. After all, technological evolution is a process largely shaped by geopolitics.[3] Science, innovation, technology, and industry have catalyzed societal transformations throughout history; these developments subsequently influenced the ways that states developed and employed technologies.[4] The most powerful nations have built advanced innovation ecosystems, supported by research and both public and private investment. These ecosystems form a critical foundation of their technological power: the capacity to harness innovation and employ new technologies to modify systems and catalyze change on the global stage. As geopolitical competition unfolds in an era of interdependence, technological power enhances sovereignty.

Yet, despite growing policy interest in countries' advancements with critical and emerging technologies, there are few tools to facilitate comprehensive comparisons across interconnected technology sectors. Some notable efforts include the Stanford Institute for Human-Centered AI's *Artificial Intelligence Index Report 2024*, the Australian Strategic Policy Institute's Critical Technology Tracker, and the Lowy Institute's Asia Power Index. The primary goal of the Index is to fill this gap, facilitating comparative, cross-sector technology analysis for informed geostrategic decision-making. It presents data through an interactive Dashboard with adjustable parameters, enabling users to generate tailored data visualization on the geopolitics of technology. A policymaker or strategist can use this Index Dashboard, for instance, to explore the sectors in which countries lead or lag, evaluate the strengths and weaknesses of countries across technology sectors, and assess changes over time as new data is incorporated.

The White House Office of Science and Technology Policy's 2024 updated list of critical and emerging technologies guided the selection of the five sectors featured in this Index: AI, Biotechnology, Semiconductors, Space, and Quantum.[5] Many countries and international organizations—such as Australia, the United Kingdom, the European Union, Germany, China, Japan, South Korea, and NATO—have also published technology lists highlighting similar sectors of interest.[6] Innovation in these five areas helps drive progress across other technology sectors; advancements in one can facilitate greater efficiency, capability, and competitiveness across others. These sectors are also vital to the national security and strategic autonomy of states, helping governments navigate future geostrategic challenges and seize new opportunities.[7]

**Actors Included in the Index**

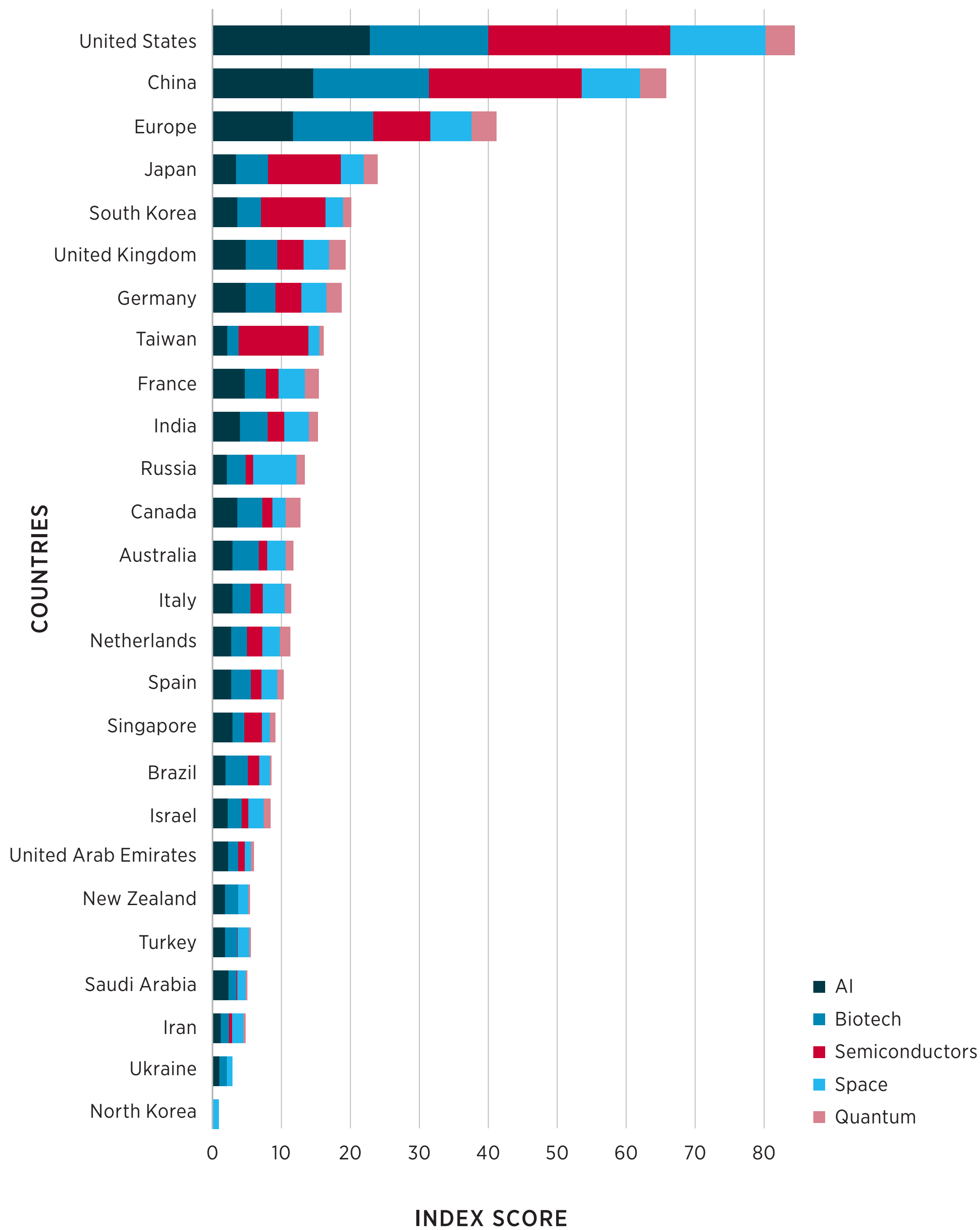
Australia, Brazil, Canada, China, Europe, France, Germany, India, Iran, Israel, Italy, Japan, Netherlands, New Zealand, North Korea, Russia, Saudi Arabia, Singapore, South Korea, Spain, Taiwan, Turkey, Ukraine, United Arab Emirates, United Kingdom, United States.[8]

**Technology Sectors Measured in the Index**

Artificial Intelligence, Biotechnology, Semiconductors, Space Technologies, Quantum Technologies.

The methodology behind the Critical and Emerging Technology Index can be broadly separated into three distinct parts.[9] First, 48 key dimensions across all the technology sectors—referred to in this report as pillars—were identified, along with corresponding sub-metrics designed to capture a country's proficiency in each sector. These pillars fall into two categories: four to five fundamental cross-sector pillars consistently applied across all critical and emerging technologies (including Economic Resources, Human Capital, Security, Regulatory, and Global Player), and three to five sector-specific pillars, which vary by sector and are tailored to reflect unique characteristics of the technologies and systems in question. In the Index's space sector, for example, Economic Resources and Domestic Launch Capability serve as fundamental and sector-specific pillars, respectively. Second, over 3,375 individual data points were compiled, organized, and validated to comprise sub-metrics under each pillar. Third, the data was reviewed and normalized to meaningfully measure countries and preserve each sub-metric's relative importance. Altogether, this process enabled the assignment of weights to sectors and pillars, which were multiplied by each country's normalized scores and summed to generate either sector-specific scores or final composite scores for countries across all sectors. Using the Dashboard, users can personalize this process, inputting their own sector and pillar weights to create tailored assessments. (For more information on the methodology of the Index, see the Annex of this report.)

The default sector weights used in the Index were generated using a structured scoring method that reflects the relative strategic value of the different technology sectors. This method began with identifying six criteria that define each technology sector: geopolitical significance, systemic leverage, GDP contribution, dual-use potential, supply chain risk, and time to maturity.[10] Technologies were then rated on a scale of one to five across these criteria; these ratings were multiplied by corresponding criteria weights, with the sum of these products yielding a comprehensive raw score for each sector.[11] Raw scores were then normalized and rounded to generate the final sector weights: 35% for Semiconductors, 25% for AI, 20% for Biotechnology, 15% for Space, and 5% for Quantum.[12] Once again, rather than being a conclusive assessment of the sources of technological power, these sector weights are provisional and intended as a reference point for further analysis.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INDEX SCORE
AI
Biotech
Semiconductors
Space
Quantum

## Main Themes

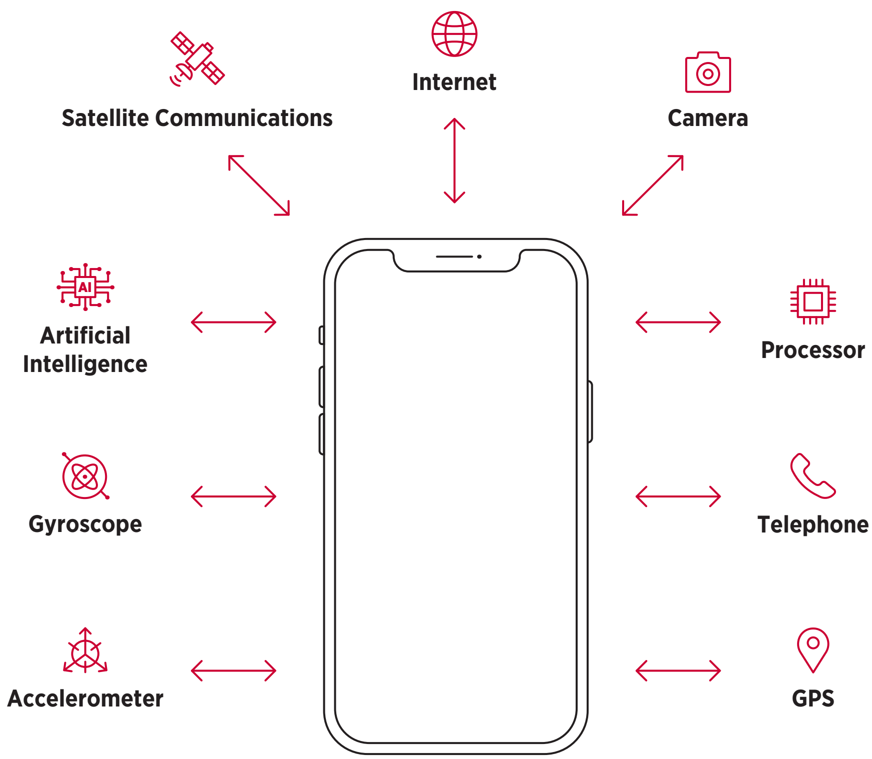
The Index shows that the United States is strong across all critical and emerging technology sectors, with a pronounced lead in space and artificial intelligence. The United States' performance is largely driven by economic resources and human capital, reflected in the scale of American public and private investment and its heterogeneous, world-class research workforce. The country's decentralized innovation ecosystem—where resources, ideas, and authority are distributed across a myriad of federal agencies, state and local programs, universities, start-ups, and corporations—enables actors to expediently pool expertise and scale innovations without being constrained by a single central authority. This decentralization remains a core driver behind American dynamism and technological power.[13] However, cuts to academic research funding and growing political polarization are hindering the United States' ability to strategically shape the public and private allocation of resources. The American innovation ecosystem has delivered strong results over the past several decades, but it currently stands to lose talent and funding due to changing federal policy. Washington must reverse volatile actions on trade and end clashes with academic institutions if it wants to preserve U.S. gains and further the American lead in critical and emerging technologies.

The Index also shows that while China largely trails the United States in critical and emerging technologies, it remains competitive and is steadily closing the gap across multiple technological sectors. Despite recent, high-profile advances in indigenous capabilities, China remains behind the United States in semiconductors and AI due to continued reliance on foreign equipment, a lack of early-stage private research ecosystems comparable to the West, and shallower capital markets than those in Western economies. The U.S. lead over China, however, narrows considerably when it comes to biotechnology and quantum. Both are newer, rapidly evolving sectors that operate largely outside traditional technology ecosystems. More specifically, China's strengths in biotechnology stem from its dominance in pharmaceutical production and manufacturing. In quantum, its strength lies primarily in sensing and communications. China, like the United States, draws strength from its economic resources and human capital—two foundational pillars that are necessary to drive progress across all critical and emerging technologies. These strengths, combined with China's narrowing gap in biotechnology and quantum technologies, illustrate how Beijing uses scale and centralized planning to seize and create new opportunities: cutting China's reliance on imports, compelling foreign firms to produce and innovate within its borders, and boosting its industrial competitiveness.[14] China's rise as a technology powerhouse is also reflective of a growing consensus that strategic sectors need government backing to stay competitive, particularly when facing off against heavily subsidized rivals. Still, China remains constrained by large structural challenges: slowing growth, mounting debt, and industrial overcapacity, among others.[15]

No other nation rivals the United States and China in critical and emerging technologies. A second tier of countries follows well behind the U.S.-China duopoly, with scores steadily declining from one country to the next. These countries, in order, are: Japan, South Korea, the United Kingdom, Germany, Taiwan, France, India, Russia, Canada, Australia, Italy, the Netherlands, Spain, Singapore, Brazil, Israel, the United Arab Emirates, New Zealand, Turkey, Saudi Arabia, Iran, Ukraine, and North Korea.

This balance of power in critical and emerging technologies, however, shifts when Europe is treated as a unified whole. Aggregating the technological strengths of countries in Europe—France, Germany, Italy, the Netherlands, Spain, Turkey, and the United Kingdom—gives the region a collective standing that amounts to roughly half of the U.S. total and two-thirds of China's. Sector by sector, Europe ranks third in AI, biotechnology, and quantum technologies, but continues to trail Japan, Taiwan, and South Korea in semiconductors, and Russia in space. Still, to foster technological power across Europe as a whole, the region must deepen market integration, coordinate and merge political institutions, and create innovation and capital markets that encourage greater dynamism.

In today's current geopolitical landscape, even small advancements—particularly in biotechnology and quantum—could have significant ramifications for the future balance of power. After all, technological convergence means that advancements in one sector can create network effects that accelerate progress in other sectors and shape future technologies in ways that are not immediately clear.[16] Powerful AI models, for instance, are already helping researchers accelerate drug discovery and predict protein structures, while quantum research is driving the development of improved semiconductor materials for next-generation computer chips. These positive feedback loops also embed first-mover advantages into the system, creating path-dependent gains that grow harder to dislodge as technologies interconnect and co-evolve.[17]




Technological convergence complicates efforts to govern or forecast the impact of critical and emerging technologies. It also means that countries seeking great power status must maintain an edge across a constellation of critical and emerging technologies.[18] This does not mean that smaller states are out of the game. The countries that build on their strengths and coordinate with partners abroad can secure lasting economic prosperity and security within their regions or geopolitical blocs. For example, policymakers in Ottawa have helped Canada become a quantum powerhouse: although it represents just 0.5% of the world's population, the country is home to five percent of global quantum talent, has authored over 1,000 of the 75,000 quantum research papers published on arXiv in 2023, and has committed $360 million Canadian dollars through its 2023 National Quantum Strategy to support talent development and international collaboration in quantum sensing, computing, and communications.[19]

Still, managed or emergent interdependence comes with external risks. Exogenous shocks—such as global pandemics or interstate wars—can abruptly sever cross-border supply chains, leaving countries that specialize too narrowly unable to secure critical inputs or export goods and services. To mitigate these risks, many governments are reshoring specific industries, friendshoring to allies and partners, and tightening export controls on critical and dual-use technologies. These changes are unfolding in both global and regional contexts; after all, most trade and investment is heavily regional, and so-called 'global' supply chains rarely stretch end to end.[20] These are often used within broader national strategies to balance cost efficiency and resilience. Still, the challenges of enforcement, tensions between competition and innovation, and the complexity of global trade networks mean that no single policy can address every risk; tradeoffs are unavoidable.[21] Governments must strike the right balance in how they use these tools.

While this Index and Report map the global landscape of critical and emerging technologies, they do not account for shorter-term developments. As technology evolves, the way that sectors and cross-cutting pillars are assessed should evolve with it. Readers should use the flexible modeling feature of the Index Dashboard to adjust weights, challenge underlying assumptions, and test different analytic inputs.

# Artificial Intelligence

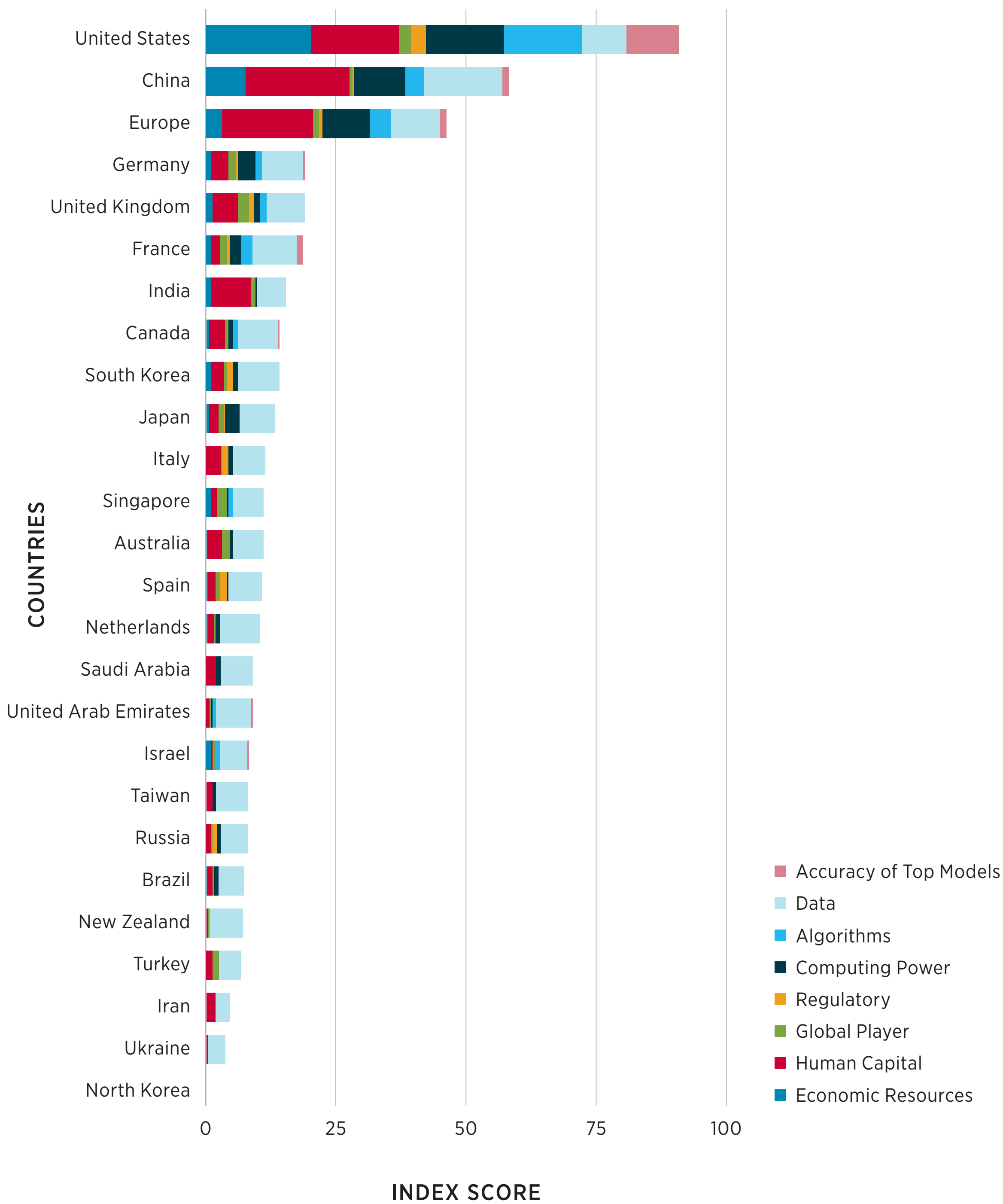
## Background

Artificial Intelligence (AI) describes the ability of computers and machines to execute tasks that normally rely on human cognition: analysis, inference, problem-solving, interpretation, and decision-making. The development of AI models generally follows several key stages. After defining the task, data scientists collect, preprocess, and format relevant data. Engineers select or develop an appropriate algorithm based on the task and data type—whether supervised, unsupervised, or reinforcement learning—and pair it with a fitting model architecture. The model is then trained, evaluated, and tested on this data. This results in a version of the model ready to be deployed; the performance of the model, however, still needs to be regularly monitored and updated with new data over time.[22]

The current race for AI dominance, driven by both states and private firms, is about more than just computing power. AI is becoming a foundational capability across all sectors of society, boosting productivity and augmenting human labor and decision-making. In 2018, the U.S. National Security Commission on Artificial Intelligence stated that "AI systems will… be used in the pursuit of power," and political leaders and scholars increasingly frame the development of AI systems as an integral competition shaping the future of governance and the balance of power in the years ahead.[23]

U.S. firms such as OpenAI, Google, and Anduril are leading in the development and employment of advanced AI systems, creating state-of-the-art models for applications ranging from language and data analysis to autonomy and robotics.[24] In China, companies such as DeepSeek are setting new standards in cost efficiency, lowering development expenses through lean model architectures and optimized training pipelines.[25] European firms, including France's Mistral—best known for its open-source large language models—are also propelling innovation and contributing to European AI governance initiatives centered on transparency, ethical design, and regulatory compliance.[26] Together, these international forces fuel a global market characterized by research and increasing adoption of AI systems for different commercial and military applications.

This report's analysis of AI is based on eight pillars. The greatest weights were assigned to the Economic Resources and Human Capital pillars, since funding and skilled personnel form the bedrock of any AI ecosystem. Technical factors captured in the Algorithms, Computing Power, Data, and Accuracy of Top Models pillars are also crucial as determinants of AI performance and efficacy. Complementing these technical foundations, the Global Player and Regulatory pillars track the institutional environment shaping AI advancement, though with lower weights to acknowledge their supporting, rather than foundational, influence on AI capabilities.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INDEX SCORE
Accuracy of Top Models
Data
Algorithms
Computing Power
Regulatory
Global Player
Human Capital
Economic Resources

## Key Judgments

1. **The United States is ahead in AI, with China and Europe roughly tied in the second tier.** While China maintains an absolute lead in human capital and data and is far ahead of Europe in economic resources, it fares similarly to Europe in terms of computing power and algorithms.[27] The result for overall scores is a far greater gap between the United States and China compared to China and Europe. Data, compute, and human capital largely determine competitive advantage—nations that amass quality datasets, deploy computing resources efficiently, and develop AI talent can leap ahead of other countries. Meanwhile, mid-tier and lower-ranked countries consistently struggle with minimal research and development, creating persistent bottlenecks to innovation and deployment.

2. **The United States has a considerable advantage in AI, but China has made significant progress and enjoys unique advantages that will challenge the American AI lead in the next decade.** The United States dominates in terms of its economic resources, computing power, and algorithms, while China leads in terms of data and human capital. The 2025 release of DeepSeek's R1 model and Alibaba's Qwen3 family of models, however, demonstrated that the U.S. lead in AI may be more vulnerable than previously assumed.[28] Maintaining a lead in AI demands ongoing attention and financial commitment to develop, adopt, and integrate systems across both commercial and government applications.[29] The great progress China has made in AI over the last two years, particularly with regard to model performance and cost-optimized training, underscores the importance of not only pioneering key technologies but also leveraging initial progress to advance growth in a variety of industries.[30]

3. **Europe's strength in AI is largely derived from human capital, but the region trails in algorithms, computing power, and economic resources.** Fragmented innovation among national startups limits scalability compared to Silicon Valley, and although Europe has large amounts of raw data, European Union data protection regulations complicate large-scale model training.[31] Without the establishment of greater incentives for cross-border commercial growth, coordinated initiatives such as a pan-European AI Moonshot Fund, or a more favorable regulatory environment, Europe risks continuing to export ideas while importing commercial models, marginally shaping the governance of AI without capturing the strategic value of adopting and integrating AI systems.

## Additional Findings

- **The United States excels in terms of its large number of AI models with high accuracy; France and China follow, albeit at a considerable distance.** U.S. models consistently outperform other countries' models in mean win rate—the proportion of times a model performs better than others across a myriad of tests in subjects such as literature, media, science, and math.[32] This performance edge is reinforced by the volume of accurate U.S.-based models, widespread user access, and strong underlying data pipelines. Together, these elements create a self-reinforcing cycle of model effectiveness, also aiding the integration and use of AI models by both government and commercial customers.

- **Countries with strong human capital or data but limited computing power harbor unrealized AI potential.** India and Brazil's limited computing power is currently holding them back from taking advantage of their strengths in human capital and data. The increasing availability of cloud-based graphics processing units and open-source models, however, could help accelerate their progress in AI. How quickly these countries can advance is partly contingent on the policies the Trump administration develops to replace the Biden administration's U.S. Regulatory Framework for AI Diffusion.[33]

- **China dominates in raw human capital for AI, followed by Europe, the United States, and India.** Though the data used to calculate human capital in this Index represent the number of high-impact scientific publications rather than per capita measurements, scale still matters: a larger pool of competent individuals increases the chances of cutting-edge innovation and startup proliferation. Irrespective of disparities in compute access or regulatory readiness, this sheer volume of skilled personnel helps drive indigenous research output, model training, and domestic applications for commercial and government use.

- **Cloud computing infrastructure is fundamental to the development and deployment of AI systems, yet it remains difficult to measure.** The United Arab Emirates is a prime example; while Abu Dhabi currently has relative weaknesses in terms of measured venture capital investment in AI, the emirate actually controls substantial computing power through G42, challenging conventional methods of assessing the economic resources ultimately being channeled toward AI development and deployment.[34] Without policy approaches that adequately address cloud computing, current export control measures will likely fall short of their enforcement goals and objectives. Indeed, the U.S. Regulatory Framework for AI Diffusion attempts to address this gap, but without detailed intelligence on cloud-based AI computing operations and substantial penalties for compliance violations, Western powers will struggle to control the proliferation of advanced AI systems, especially among competitors and adversaries.[35]

- **No actors beyond the United States, China, and Europe have a full-spectrum AI stack, but other nations can still build meaningful advantages in AI through vertical or regional specialization.** Displacing the United States, China, and Europe would require large, simultaneous progress in computational power, economic resources, and algorithms; this is an immensely difficult task for any single nation. China has yet to field viable alternatives to the dominance in graphics processing units and software that Nvidia (with its proprietary architecture) and Taiwan Semiconductor Manufacturing Company provide for the United States.[36] Yet the modular structure of AI value chains—spanning data pipelines, foundation models, and domain-specific fine-tuning—creates opportunities for influence without comprehensive AI capabilities. Countries that are neophytes to the AI race can invest in their strengths to carve out durable niches, influencing global standards and capturing outsized benefits in terms of productivity in the private sector and government. Examples include Japan and Germany in robotics-AI integration, Canada in developing safety and alignment tools for industrial equipment, and Brazil in agricultural data.

# Biotechnology

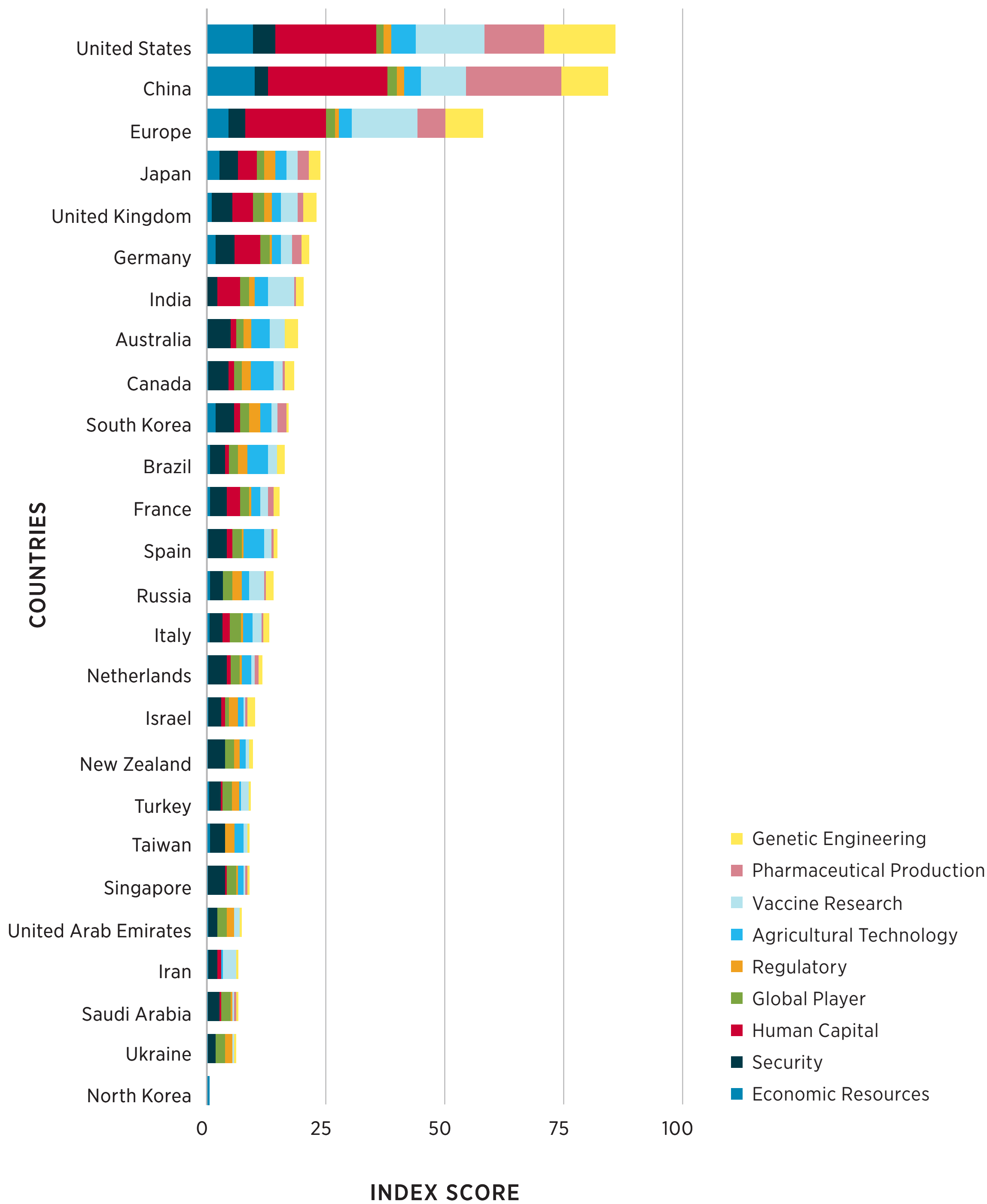
## Background

Biotechnology refers to the systems enabling the modification of living organisms and their components for specific applications. While human societies have long used biological processes, such as fermentation and selective breeding, breakthroughs in the late 20th and early 21st centuries—such as the development of mRNA platforms and CRISPR-Cas9—have expanded biotechnology into a field capable of reprogramming life at its fundamental level.[37] Today, biotechnology spans several domains: genetic engineering (altering nucleic acids through techniques such as gene editing); bioprocess engineering (using organisms to produce goods by leveraging metabolic pathways); biomolecular analysis and engineering (analyzing and manipulating biological molecules); environmental biotechnologies (employing living systems to clean or enhance ecosystems); and synthetic biology (designing entirely new biological parts or systems).[38]

Governments need biotechnology to understand and enhance the health of their societies.[39] Their most visible applications span medicine, agriculture, energy, and sustainability; for instance, mRNA vaccines, aquaculture, and the development of bioengineered fuels. The COVID-19 pandemic demonstrated how nations with advanced biotechnology capabilities were able to better protect themselves: rapidly sequencing the virus, developing diagnostics, and deploying vaccines. This technological edge is contingent on the integration and convergence of different technological ecosystems, such as bioinformatics, AI, and high-throughput computing.[40] These synergies are simultaneously accelerating the discovery of new biological compounds and widening the gap between nations that can integrate these tools and those that cannot. The growing accessibility of biotechnology also elevates the risk of accidental or deliberate misuse. In this respect, governments and private firms around the world are becoming more cognizant of the need to manage the risks that biotechnology poses; as much as biotechnology can be used to cure diseases, it can also be used to facilitate the creation of new and deadly pathogens.

Governments, companies, and research institutes are currently shaping the future of biotechnology. China's BGI Group has grown from its origins as a small state-backed research institute into a far-reaching genomics powerhouse that now has a diversified portfolio in everything from animal cloning to diagnostic testing.[41] Across the Pacific, American firms such as Moderna and Colossal Biosciences have introduced new innovations in genetic engineering, the former notably introducing a COVID-19 mRNA vaccine authorized for use in the United States in December 2020.[42] Europe hosts its own biotechnology giants, including Germany's BioNTech and Switzerland's Novartis.[43] The industry's shifting global dynamics became particularly evident when Monsanto, once a dominant American agrochemical and biotechnology firm known for genetically engineered crops, fell under German ownership after Bayer AG acquired the company in 2018.[44]

This report's analysis of biotechnology is based on nine pillars. The greatest weights Analysis in this sector prioritizes Human Capital, Economic Resources, and other pillars representing key aspects of biotechnology capability (Pharmaceutical Production, Genetic Engineering, and Vaccine Research) with the highest weights. This is because of these pillars' direct impact on innovation and crisis response, as demonstrated during the COVID-19 pandemic. Lower weights were placed on Agricultural Technology, Security, and the pillars representing aspects of biotechnology governance (Global Player and Regulatory) because they do not directly reflect the advancement and diffusion of these technologies.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INDEX SCORE
Genetic Engineering
Pharmaceutical Production
Vaccine Research
Agricultural Technology
Regulatory
Global Player
Human Capital
Security
Economic Resources

## Key Judgments

1. **Among the technologies examined in this Index, China has the most immediate opportunity to overtake the United States in biotechnology; the narrow U.S.-China gap suggests that future developments could quickly shift the global balance of power.** The United States and China perform similarly in biotechnology overall, with China's strengths underpinned by its human capital. The United States excels in security, genetic engineering, vaccine research, and agricultural technology, bolstered by private-sector innovation and public-private partnerships. China has dominance in pharmaceutical production through extensive, large-scale public investments and state-backed manufacturing.

2. **Cross-national gaps in human capital, pharmaceutical production, genetic engineering, and vaccine research highlight these areas as bottlenecks to building biotechnology power.** These four areas show the highest variance among all measured pillars in the biotechnology sector and, based on the weighting used in this analysis, collectively contribute 75% to the total sector score.[45] Advanced research cannot be developed or applied for real-world solutions without the necessary workforce or a strong biomanufacturing base, just as expertise in genetic engineering and vaccine development is essential for the rapid innovation needed during health emergencies such as the COVID-19 pandemic.

3. **Europe trails the U.S.-China biotechnology duopoly not for lack of potential, but due to decentralized institutions and under-leveraged resources.** While Europe performs well in vaccine research and security and reasonably well in human capital, the region continues to lag behind the United States and China, particularly in economic resources and pharmaceutical production. To avoid falling further behind and reach its full potential in the bioeconomy, Europe must strengthen the European Union Single Market, better integrate with non-European Union partners, coordinate cross-national public funding efforts, and implement centralized pathways for approving the testing and deployment of biotechnologies.

## Additional Findings

- **Significant private sector funding provides the capital needed to make Japan a rising leader in the field; however, it struggles at the moment to turn this capital into biotechnology products.** Japanese private-sector funding in biotechnology is nearly triple that of the United Kingdom and about double that of Germany, suggesting a healthy appetite in the country for startups and innovation. Given this large quantity of capital, however, Japan does not have a proportional lead in vaccine research, pharmaceuticals, and genetic engineering. This points to a bottleneck between investment and outcomes, stemming from regulatory delays, weak systems for technology transfer, risk-averse funding, and siloed industry actors—challenges that Japan needs to address to better translate biotechnology research into real-world therapies and products.[46]

- **Japan's regulatory environment is uniquely amenable to rapid approval for human-based research, which is unusual compared to other nations with notable achievements in gene editing.** The United States and the United Kingdom, for example, have placed high restrictions on human gene editing that only permit it in exceedingly rare cases. Germline gene therapy, specifically, is entirely prohibited in the United States. Meanwhile, stem cell therapy research has been accelerated by government-led national strategies to promote quick transitions to clinical trials since 2011 in Japan.[47] Some of this pointed interest may be partially explained by Japan's extreme demographic aging, which both domestic and international investors view as a unique research catalyst.[48]

- **South Korea has not yet converted its large public and private capital into equivalent biotechnology strengths, but this is a nation to watch, given Seoul's renewed interest in the sector.** Despite possessing one of the highest amounts of private sector funding, in addition to high government funding, South Korea has produced weaker research power compared to other similarly funded countries. In 2023, the South Korean government released several plans to improve the country's biotechnology industry, particularly as related to agricultural biotech—new initiatives are likely in development.

- **Australia's high score reflects years of targeted reforms to build a layered, risk-based biosecurity system; still, rapid response remains a persistent weakness both in Australia and worldwide.** Canberra's strength in early detection and reporting of epidemics contributes significantly to its biosecurity performance, accounting for over a quarter of its sector ranking in the Index.[49] Other Western governments can take a page from Australia's playbook of steady legislative reform and cross-sector coordination—evident in the establishment of the Health Protection Principal Committee in 2009, the passage of the Biosecurity Act in 2015, and release of its National Biosecurity Strategy in 2022.[50] Yet all countries, including Australia, still fall short in their rapid response capabilities. Governments worldwide need to do better by conducting more comprehensive exercises, developing and deploying new risk communication mechanisms, and strengthening links between public health and security authorities.[51]

# Semiconductors

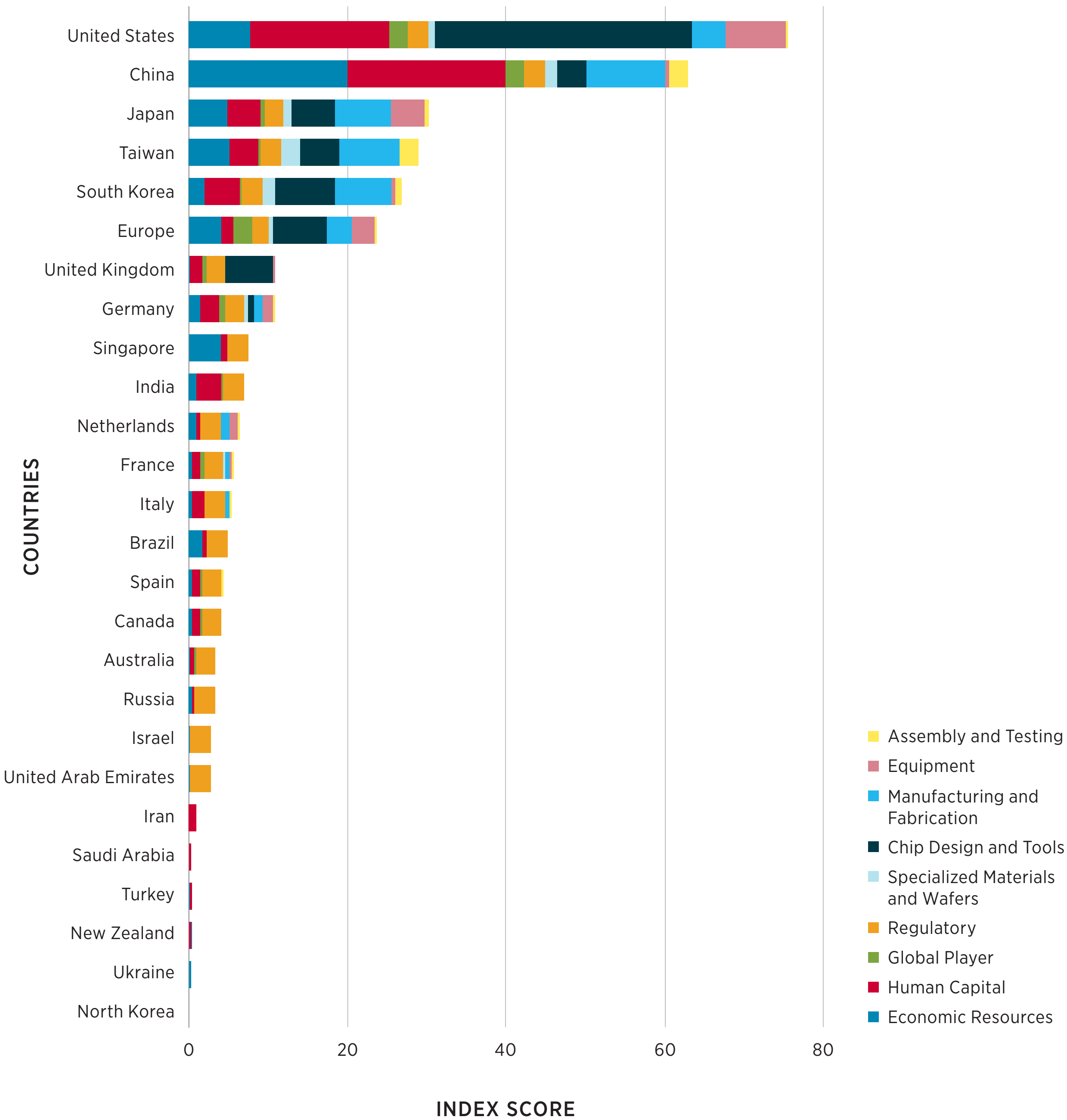
## Background

Semiconductors are materials that can conduct or block electrical current, though the term commonly refers to integrated circuits—compact chips containing transistors, resistors, and capacitors.[52] These chips form the foundation of all modern computing systems by enabling the processing, storage, and transmission of data.[53] The manufacturing of semiconductors relies on a series of highly specialized ecosystems and firms, starting with the advanced software and design needed to fit billions of transistors onto a chip. Then there are the actual silicon wafers themselves, along with the complex equipment that carves designs onto them. This is followed by the formation of transistors by fabrication facilities, using processes and techniques refined over decades and through the investment of billions of U.S. dollars in research and development. Lastly, the chips are packaged and distributed to device manufacturers for use in smartphones, vehicles, and other electronic devices.[54]

Although the complexity of the semiconductor supply chain ensures that they will remain part of a globally integrated industry, governments have increasingly come to view them as a critical aspect of national security. Recent geopolitical shocks have revealed the world's heavy reliance on semiconductors and the vulnerability of its interwoven supply chains.[55] Moreover, escalating U.S.-China tensions and Beijing's increasing belligerence towards Taipei have prompted governments and companies to assess the risk of aggression against Taiwan—home to the Taiwan Semiconductor Manufacturing Company, which manufactures 70-90% of the most advanced transistors.[56] At the same time, the race for more powerful AI capabilities has driven demand for advanced chips, particularly graphics processing units, thousands or even millions of which power the data centers used to train AI models.[57] Indicative of this massive demand is the U.S. firm Nvidia, which produces high-end graphics processing units and saw its market capitalization more than triple from January 2023 to January 2024.[58]

Semiconductors have become a strategic priority for the United States since the Biden administration's first series of expansive export controls targeting China in October 2022.[59] Countries aim to have domestic control over semiconductors, spanning legacy and high-end devices, to protect themselves in case of foreign catastrophe.[60] Washington and Beijing also want high-end chips to develop the AI systems both see as essential for gaining the upper hand in their intensifying security competition. Through U.S. export controls, Washington has leveraged its strengths in design and manufacturing equipment, alongside partnerships with Japan and the Netherlands, to limit China's access to cutting-edge semiconductors. At the same time, many countries—China most notably—have shown that state subsidies and guidance are essential in fostering domestic industry amidst global competition.[61]

This report's analysis of semiconductors is based on eight pillars. The greatest weights are assigned to Chip Design and Tools, Economic Resources, Human Capital, and Manufacturing. This is because these pillars represent the critical bottlenecks: sophisticated design software enables cutting-edge architectures, massive capital investment funds necessary facilities and critical infrastructure, specialized talent drives innovation, and advanced manufacturing techniques determine production quality and yields. Less weight is given to Equipment, Assembly and Testing, Specialized Materials and Wafers, Global Player, and Regulatory pillars to reflect their supporting role for a country's semiconductor capacity.



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INDEX SCORE
Assembly and Testing
Equipment
Manufacturing and Fabrication
Chip Design and Tools
Specialized Materials and Wafers
Regulatory
Global Player
Human Capital
Economic Resources

## Key Judgments

1. **No country has complete, end-to-end control of a supply chain for advanced semiconductors.** The United States excels in chip design and tools, as well as equipment, but lags in manufacturing and fabrication. China leads in economic resources, assembly and testing, and manufacturing and fabrication, with a significant edge in the mining and refining of the inputs for materials and chemicals. However, China remains relatively weak in equipment, specialized materials, and wafers.[62] Taiwan dominates in specialized materials and wafers as well as manufacturing and fabrication, but depends on foreign equipment. Japan and South Korea are both strong in human capital, chip design and tools, and manufacturing and fabrication, but leading firms in both countries remain heavily reliant on the Chinese market.[63]

2. **The dominance of the United States, Japan, Taiwan, and South Korea in semiconductors persists at critical chokepoints of the supply chain: advanced manufacturing and fabrication, chip design and tools, and equipment.** These pillars have the greatest variance among all included in this Index due to high costs and technical barriers. While many countries are investing heavily to close these gaps, capital alone is unlikely to be sufficient to establish an end-to-end semiconductor production capability; if countries aim to break free from dependence on the current leaders, they will need to simultaneously secure equipment and advance chip design.

3. **Although China leads other countries in chip manufacturing by site capacity, it faces extreme challenges in overtaking global leaders Taiwan and South Korea in *advanced* chip manufacturing.** Historically, countries that lead in advanced chip manufacturing have only been usurped when other countries already established in lower-end chip manufacturing make innovative breakthroughs.[64] While China has lower-end chip manufacturing experience and lower operational costs than Taiwan and South Korea, it is trying to achieve breakthroughs in multiple segments of the industry while also being subject to U.S. restrictions on using leading designs or equipment—an unprecedented battery of barriers. Assessing China's progress is hard, however, because U.S. export controls incentivize Chinese firms to downplay their advancements.[65]

## Additional Findings

- **Countries that lead in semiconductor power have invested the most to keep their firms in the lead.** After China and the United States, the countries that have pledged the most public funding for domestic semiconductor investment currently dominate the semiconductor value chain: Japan, South Korea, and Europe (led by Germany), with Taiwan ranking lower but still high among all 25 countries. Japan has announced over $11 billion U.S. dollars in subsidies for Rapidus, its domestic semiconductor startup aimed at producing leading-edge chips by 2027.[66] South Korea last year published its plan to build the largest semiconductor cluster by 2047 and is investing in both its traditionally dominant sector of memory as well as logic, where Taiwan's firms now lead.[67] The European Union's European Chips Act will mobilize around $20 billion U.S. dollars to attract foreign firms and promote domestic ones.[68] Government support has always played a role in semiconductor power—something that the leading states recognize.

- **The United States' semiconductor strengths were built up in a globalized economy, but export controls challenge this model.** American producers of semiconductor manufacturing equipment, in particular, have suffered as U.S. export controls have limited access to the China market. While the cutoff from Chinese firms has also affected chip design firms—the sector of the semiconductor industry the U.S. most dominates in—the boom in sales of AI chips has more than recompensed leading design firms' losses. Equipment manufacturers must wait longer to recoup losses since their customers, chip manufacturers, shop less frequently than chip manufacturers' customers do. U.S. equipment manufacturers' reliance on Chinese sales has fueled their opposition to export controls and strengthens the case for an American "tech fund," which would share initial risk and support diversification away from China.[69]

**Nvidia and Applied Materials Under U.S. Export Controls**

The fates of U.S. chip design firm Nvidia and toolmaker Applied Materials illustrate the uneven impact of U.S. semiconductor export controls since October 2022. Between November 2024 and January 2025, Nvidia's data center revenue grew 93% year-on-year, while full-year revenue rose 142%. Applied Materials, by contrast, posted a record quarter for the same period by growing just 7% year-on-year.[70] This gap largely reflects Nvidia's extraordinary growth over the past 18 months and underscores that soaring demand for AI chips does not translate into equivalent growth in demand for chipmaking tools.

Still, recent U.S. export controls have arguably impacted Nvidia more than Applied Materials. In April 2025, the U.S. government announced that Nvidia would need licenses to export its H20 chip to China. Nvidia projected a $5.5 billion loss from this restriction—about 4.2% of its revenue of $130.5 billion U.S. dollars in fiscal year 2025. By comparison, Applied Materials estimated that export controls introduced at the end of the Biden administration cost it approximately $400 million U.S. dollars in China-related revenues, roughly 1.5% of its $27.6 billion U.S. dollar revenue for the year ending January 31, 2025.[71] This is despite the fact that U.S. export controls on Nvidia-designed AI chips have not been airtight; for example, as first reported in October 2024, Huawei obtained controlled chips from the Taiwan Semiconductor Manufacturing Company through a third-party Chinese chip design firm.[72]

- **India is working to establish itself as a semiconductor manufacturing hub, leveraging its market size and labor force, but still lags behind leading states in critical infrastructure.** Though ranking below established players in semiconductor power, the Modi government has put money and effort into the industry since declaring its aim in April 2022 "to establish India as one of the key partners in global semiconductor value chains."[73] India, already responsible for one-tenth of global chip consumption, wants to become less reliant on foreign suppliers as domestic consumer demand for chips rises. It is also growing more attractive for firms looking to shift production away from China, given its rising labor costs and geopolitical tensions with the West.[74] Even though India hosts only 7% of chip design facilities, it has nearly 20% of the world's design engineers (many working for U.S. or European firms). New Delhi has subsidized a semiconductor park in Dholera, Gujarat, as well as foreign low-end chip manufacturing and assembly, test, and packaging operations in India in the hope that India can grow their expertise in new segments of the semiconductor supply chain, but packaging leaders China, Taiwan, and Malaysia maintain a critical lead in public infrastructure.[75]

- **Germany, the biggest semiconductor power outside of the United States and East Asia, maintains chip manufacturing leadership in the European Union because of its leading role in other manufacturing-heavy industries.** Germany already manufactures many of the European Union's chips and relies heavily on legacy chips for its auto industry.[76] Berlin has recently offered more subsidies to foreign semiconductor firms to make advanced chips at home as part of the European Union's push to reduce exposure to faraway producers in East Asia, with a goal of doubling the European Union's market share in chip production from 10% to 20% by 2030.[77] The prospect of making chips alongside German automotive and advanced equipment customers is attractive, but recent delays in proposed U.S. and German fabrication facilities call into question how badly manufacturers want to set up in Germany. Following the February 2025 election, Germany's new coalition government faces critical decisions regarding semiconductor subsidies, with significant uncertainty about future funding.[78]

- **Singapore, like Germany, is using its comparative and geographical advantages to maintain a strong position in global semiconductor markets and expand into new segments.** Due to methodological limitations, Singapore's performance in fabrication and packaging is not reflected in the Index.[79] Yet for its size, Singapore commands substantial global market shares in chip manufacturing and semiconductor manufacturing equipment. Leaning on its highly skilled workforce, existing capabilities in chipmaking, and convenient location for distribution to East Asian producers, its government has rolled out training programs as well as tax incentives and refunds in the last few years to move into chip design and advanced packaging, two other segments of the supply chain.[80]

# Space

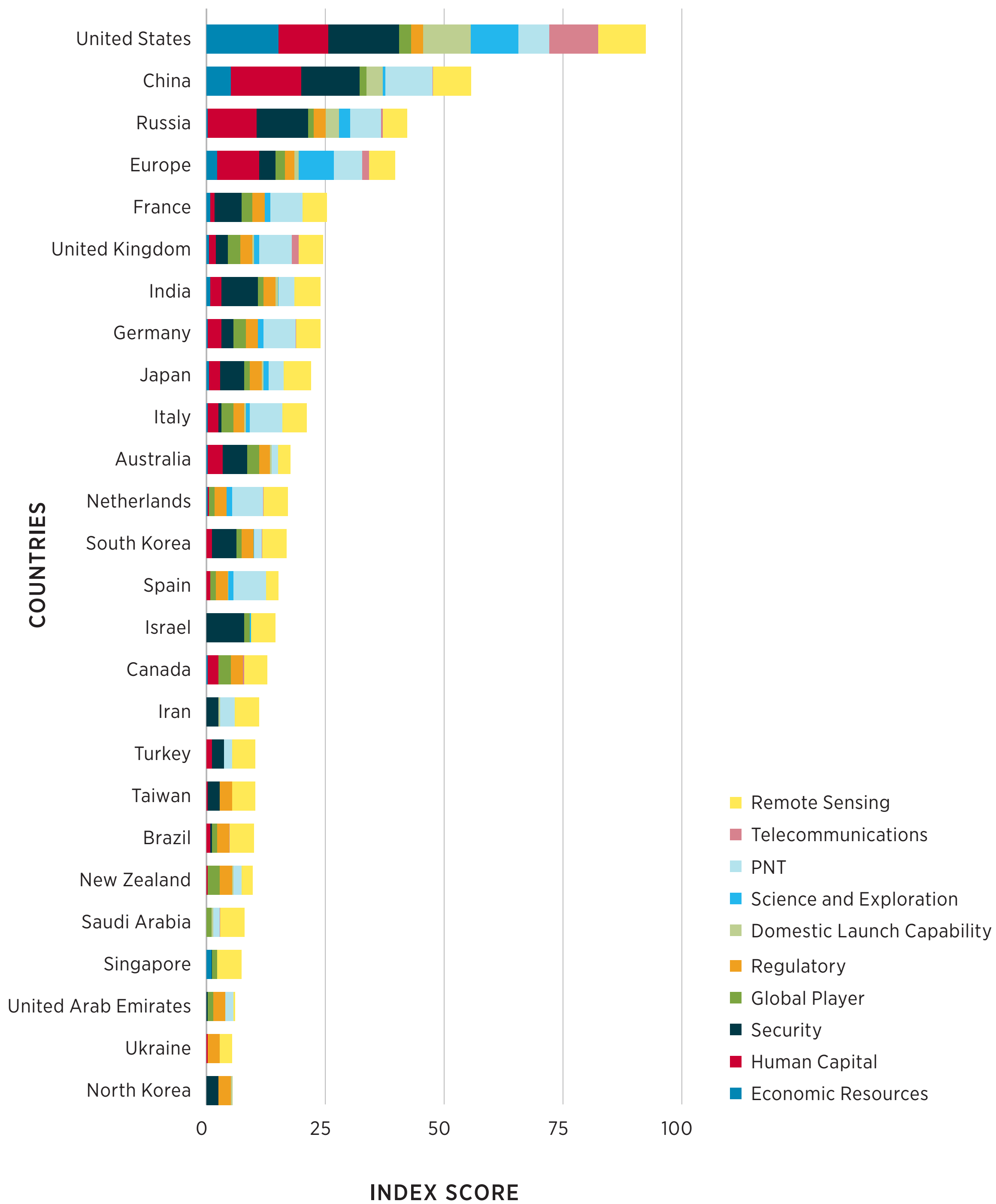
## Background

Space technology encompasses the systems that enable access to, operations within, and utilization of the space environment. The development of powerful rockets in the mid-20th century initiated physical space exploration, ushering in the current era of geopolitical competition, scientific discovery, and commercial opportunity.[81] Space technology can broadly be divided into two categories. The first includes foundational technologies that make access to and activity in space possible, such as launch systems, propulsion, power generation, and re-entry vehicles. The second includes technologies that capitalize on space's unique properties—from satellites that direct terrestrial radio navigation to space-based infrared sensors that observe the Earth and distant galaxies.

Governments now turn to space-based systems for a strategic edge, much as they once turned to new maritime technologies during the Age of Sail and aeronautical technologies in the early 20th century. Space can provide military advantage, support modern economies, advance science and scientific leadership, and underpin policy agendas to shape the future of international governance.[82] Policy leaders and military commanders rely on space-based assets—from communications satellites to missile-warning systems—for command and control, as well as intelligence, surveillance, and reconnaissance. In this respect, military capabilities in space are important not only for fighting wars, but also for deterring them. Commercial space services, including navigation, timing, and Earth observation, constitute critical infrastructure and fuel growth across a myriad of economic sectors. On the scientific front, exploration missions and research in both pure and applied science lay the groundwork for discovery and the advancement of dual-use technologies, including in robotics, advanced materials, and remote sensing. Diplomatically, engagement in new international forums and agreements presents an opportunity for countries to shape the rules and institutions governing how societies engage with space, the final physical frontier for humanity.

Governments, multinational programs, and private ventures now share the stage in driving space activity. In the United States, NASA partners with private firms such as SpaceX—pioneering reusable rockets and the Starlink broadband constellation—while the U.S. national security establishment flies and increasingly relies on a mix of military and commercial satellites.[83] China has stepped up its launch schedule and set its sights on the Moon, backed by private ventures such as iSpace.[84] It has also independently launched and currently operates Tiangong, a permanently crewed space station in low Earth orbit. While Moscow's prominence in space has faded since the Soviet era, Russia's Roscosmos continues to operate crewed Soyuz missions and sustain its longstanding presence in orbit.[85] Europe continues its activities in space through the European Space Agency, which pools resources from 23 member states to field the Ariane series of space launch vehicles.[86] Meanwhile, private companies worldwide, such as Eutelsat OneWeb's satellite broadband network, are introducing new sources of commercial innovation into the space industry.[87]

This report's analysis of Space is based on ten pillars. The greatest weights have been assigned to Economic Resources, Human Capital, and Defense and Security Assets. The pillars Domestic Launch Capability; Positioning, Navigation, and Timing; Science and Exploration; Telecommunications; and Remote Sensing pillars are all weighted slightly lower. This reflects their critical roles in enabling independent access, strategic services, and innovation. Global Player and Regulatory each have the lowest weights; after all, leadership in multilateral forums and strong legal frameworks support—but do not drive—a country's overall competitiveness in space.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75
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INDEX SCORE
Remote Sensing
Telecommunications
PNT
Science and Exploration
Domestic Launch Capability
Regulatory
Global Player
Security
Human Capital
Economic Resources

## Key Judgments

1. **The American private sector drives the United States' strong lead in space, though its vulnerabilities in orbit to Chinese and Russian military capabilities increase strategic risk.** Washington's edge stems from productive public-private partnerships that have helped the United States dramatically increase its launch frequency and payload capacity while reducing per-mission costs. American public-private collaborations also strengthen the United States' human capital, telecommunications, and economic resources. However, the United States is asymmetrically vulnerable in space, relying heavily on space-based systems for military operations and for supporting critical sectors of the American economy. China and Russia are also fielding formidable anti-satellite capabilities, offsetting the United States' lead in space and increasing its strategic exposure.

2. **A large capability gap distinguishes the top three space powers—the United States, China, and Russia—from all other nations.** The United States has a clear overall edge in space, followed by China with its ambitious state-led programs and burgeoning commercial space development. Russia occupies the third position in the Index, though much of its strength comes from Soviet-era systems and infrastructure rather than new innovation. Europe ranks fourth, followed by India, whose remarkable progress has enabled it to compete with legacy space powers through increasingly complex missions.[88]

3. **Wide gaps in human capital, remote sensing, and position, navigation, and timing indicate that these three areas are the main bottlenecks to building space power.** There is little variation in pillar scores measuring regulatory and legal frameworks, as well as participation in global norm-setting. Likewise, economic resources alone are not enough; major investments only translate into launch infrastructure, for example, when paired with sufficient human capital and research and development. On the contrary, the wide variance in countries' systems based in orbit (such as satellites for position, navigation, and timing) demonstrate that these are among the hardest capabilities to acquire; they often require indigenous launch capability, management over sensitive and classified payloads, and resilient ground-based networks capable of facilitating data transfers in austere conditions.

## Additional Findings

- **By pooling Europe's resources, the European Space Agency significantly influences the global balance of power in space.** Individually, countries such as France, Germany, and the United Kingdom fall behind global leaders, but the combined capabilities of European countries are almost on par with those of Russia and approach those of China. Europe's strength is in telecommunications, as well as science and exploration, although it falls short in terms of security and domestic launch capability. These weaknesses compel European states to rely on foreign space launch systems. Closing these shortfalls will require more extensive collaboration to develop reusable, indigenous launch systems, as well as coordinated European security initiatives.

- **The United States and Russia retain a lasting advantage from their early space race, which continues to underpin their dominance in science and exploration.** American space missions demonstrate an unmatched range and depth, while Russia and the former Soviet Union similarly achieved a high volume of missions, many during the 20th century. Although emerging players such as India and China are advancing notable missions—such as the Chandrayaan-3 and Chang'e-6 lunar probes, respectively—the institutional memory and established capabilities of legacy programs continue to confer decisive advantages, given their decades-old, world-class ground and launch infrastructure, extensive archives of mission data, and deep pools of specialized talent. As the scientific landscape broadens and drives greater international collaboration, the United States and Russia will nevertheless maintain a unique advantage.

- **Regionally, Asia presents more potent individual players.** While many European countries ranked within the top half of the Index, most countries' scores are aided by European Space Agency achievements rather than domestic ones, whereas China, Russia, India, Japan, and South Korea all possess strong independent space programs with high scores.
- **Ukraine's low ranking reflects the current state of conflict in the nation and the consequences of intertwined space partnerships.** Historically, Ukraine has possessed a robust and active space program that launched several satellites into space; nearly all space activities have been brought to a halt as a result of the Russo-Ukrainian war and the loss of access to Russian facilities and supplies, and a presumed allocation of funds entirely towards the war effort. Other international partnerships have also been halted as a result of the conflict. This shows that human capital is not enough without access to manufacturing, fabrication facilities, and equipment.
- **Israel's strengths in space disproportionately lie in its security capabilities.** With its fleet of 12 military satellites and an arsenal of cutting-edge interceptors capable of targeting objects outside the atmosphere, directed energy systems, and jamming technology, Israel clearly prioritizes military applications in space over scientific endeavors. This specialized focus limits Israel's overall ranking, despite significant strength in the security domain.[89]
- **Despite ranking at the bottom of the Index, North Korea's increasing activities in space demonstrate that it possesses notable capabilities in space.** Pyongyang's public commitment to space development and technological partnership with Russia resulted in four launch attempts in 2023 and 2024; however, since the Index only includes successful launches, North Korea received just one launch count. This, combined with a general lack of public data available on North Korea, potentially leads to an underestimation of North Korean space capabilities within this Index.
- **Iran has focused on building homegrown space surveillance and navigation systems to support its strategy of technological autarky.** Despite near-zero scores in economic resources and human capital, Tehran has been funneling talent and scarce funding into its space surveillance and positioning programs. And with the launch of the Islamic Revolutionary Guard Corps' Noor satellites and deployment of the Russian-built Khayyam Earth-observation platform, Iran now ranks with Taiwan and the Netherlands in remote sensing. Though diminutive in the overall space sector data as of now, Iran's pursuit of security and modernity—along with deepening ties to Russia, China, and North Korea—could fuel the future growth of its indigenous space capabilities.

# Quantum

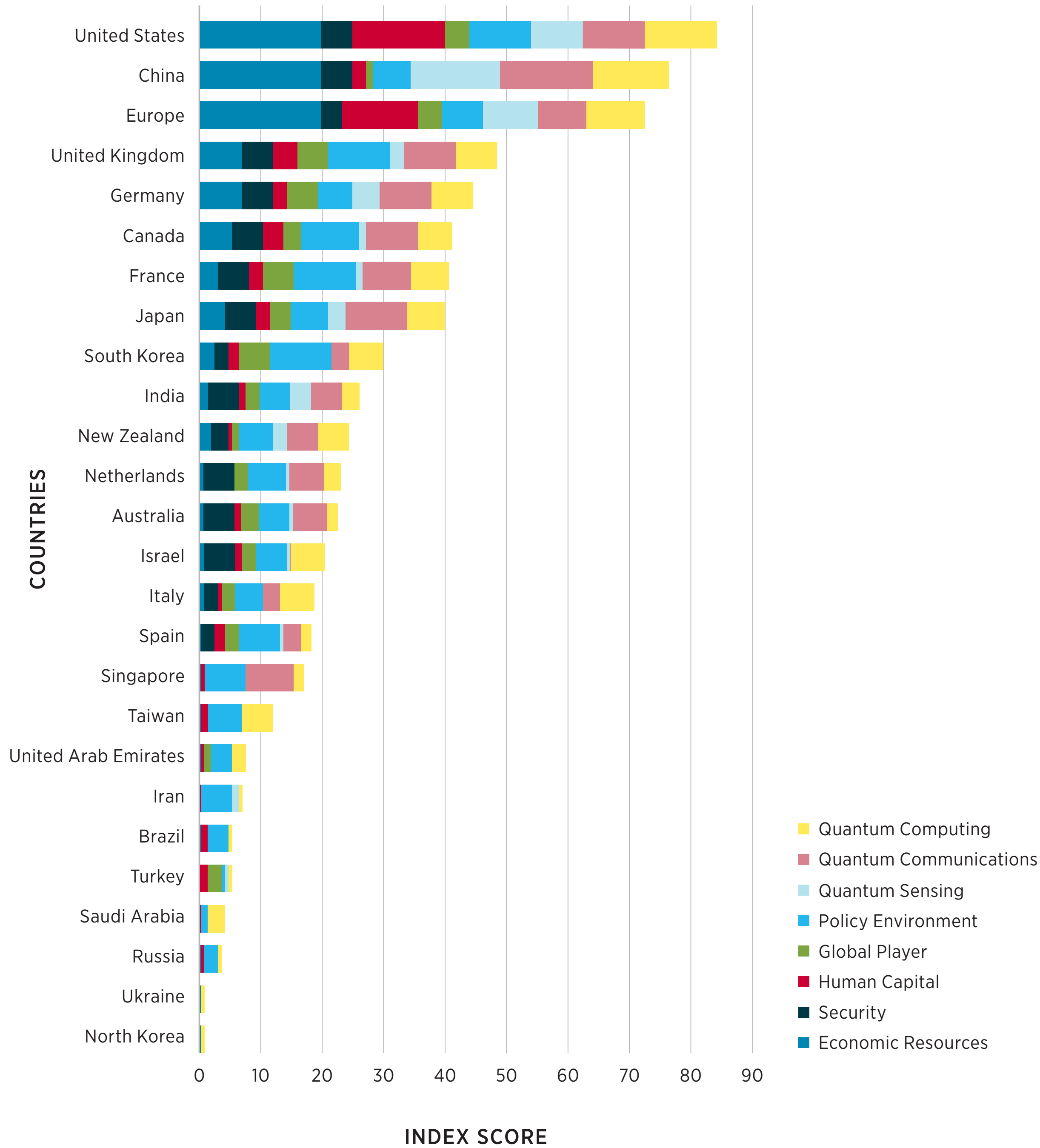
## Background

Quantum technology refers to systems that harness quantum mechanics, the behavior of particles at the molecular, atomic, and subatomic levels. Scientists in the early 20th century discovered that, at the smallest scales, particles do not follow the rules of classical physics. Rather than acting as discrete entities with definable states, particles do not settle into one configuration until measured by an external observer; until then, they can simultaneously be in a multitude of configurations, a phenomenon known as superposition.[90] Because of superposition, quantum processors with the ability to maintain coherent quantum states for sufficiently long periods of time can have the capability to pursue optimal computational paths in parallel rather than exhaustively checking every possibility, as needs to be done when using a classical computer. This could enable the employment of novel algorithms to solve previously intractable optimization and cryptographic problems.[91] In addition, technologies that take advantage of superposition will likely enable extremely accurate computational simulations of complex systems, such as those involving molecules and materials, thereby facilitating new breakthroughs in the development of next-generation superconductors, batteries, and pharmaceuticals.[92]

Quantum technology also hinges on two other fundamental phenomena of quantum mechanics: entanglement and interference. Unlike classical physics, where interactions between objects rely on direct, local contact, entanglement describes the linkage of two or more quantum systems such that an action on one affects the other(s).[93] Interference describes how the myriad of quantum possibilities can amplify or cancel each other out.[94] For quantum computing, entanglement can connect systems so that they process information simultaneously, with interference being used to highlight productive computational pathways while suppressing vitiating alternative pathways.[95] For quantum communication—characterized by ultra-secure, low-latency networks—entanglement provides the basis for methods of theoretically unbreakable cryptographic communications.[96] And by using entanglement and interference to amplify genuine signal patterns and suppress random background noise, quantum technology will likely be fundamental to the next generation of sensing and metrology systems—for instance, stealth-defeating radars, ultra-precise atomic clocks, and long-range magnetic anomaly detectors.[97]

By introducing powerful new forms of computation, the nascent quantum revolution has the potential to disrupt the global balance of power. The United States has built its quantum advantage through a multipronged strategy: corporate innovation from firms such as IBM and Google, academic research at institutions such as MIT and Stanford, and federal investment through programs under frameworks such as the National Quantum Initiative Act.[98] Through centralized development, China has built major quantum research centers, including the Hefei National Quantum Laboratory, while also launching the world's first integrated quantum communication network.[99] Furthermore, European nations are tapping into strong research institutions through collaborative initiatives such as the European Union's Quantum Flagship.[100] The international dimension of this field is illustrated by the U.K. startup Cambridge Quantum Computing merging with the US giant Honeywell to become Quantinuum, and the technological concept of "cat qubits" being instigated by the French firm Alice and Bob now being adopted by Amazon in the United States.[101]

This report's analysis of Quantum is based on eight pillars. The greatest weights were assigned to Economic Resources, Human Capital, Quantum Communication, Quantum Computing, and Quantum Sensing. These pillars form the essential foundation and technical capabilities currently shaping a country's potential to lead in the development and application of quantum technology. Although valuable for aligning national strategies and funding, the Policy Environment pillar was assigned less weight for this analysis compared to the technical domains, while the Global Player and Security pillars have the lowest weights due to their indirect influence on quantum development.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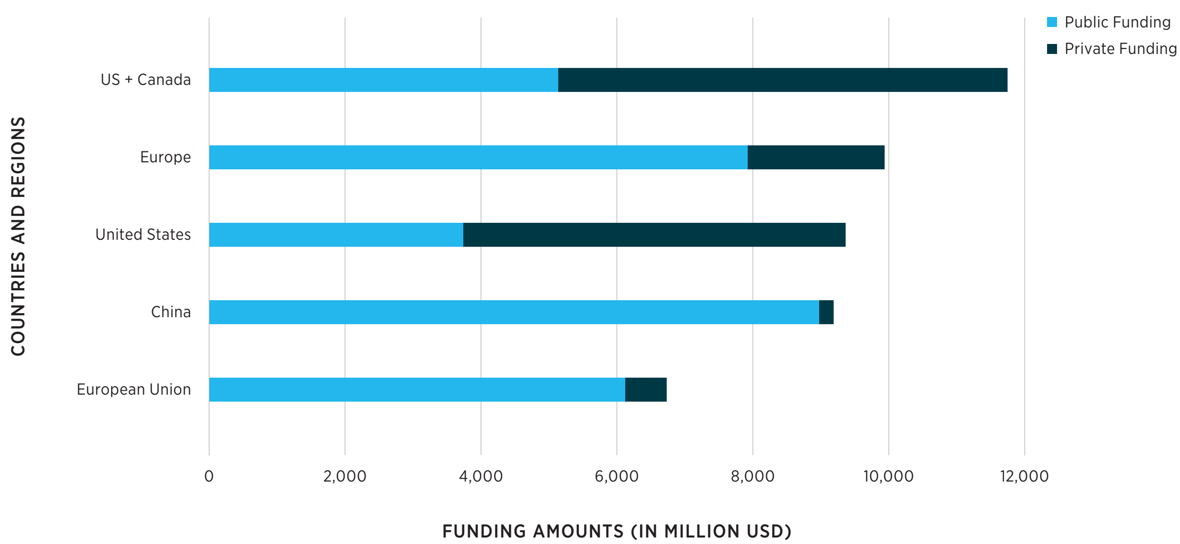
INDEX SCORE
Quantum Computing
Quantum Communications
Quantum Sensing
Policy Environment
Global Player
Human Capital
Security
Economic Resources

## Key Judgments

1. **Quantum technologies remain in an early research phase, with current efforts focused less on deployment and more on advancing early-stage concepts**. This is highlighted by the funding gap between quantum and other technology sectors; from 2008 to 2023, for example, American public and private investment in quantum technology totaled about $9.4 billion U.S. dollars—far less than the $52 billion U.S. dollars allocated under the CHIPS Act alone for semiconductor manufacturing, research and development, and talent development.[102] This relative lack of investment has contributed to the fragmented and region-specific development of quantum ecosystems. In the United States and Europe, academia generates ideas and leads foundational research, startups enable emerging technologies to be explored which may be considered too high risk for large corporations, and large corporations carry out the engineering to scale up well-vetted technologies. China takes a state-led approach, which bridges research, development, and industry. In this context, progress in quantum technologies will largely depend on how countries open or restrict the flow of talent, tools, and ideas.

2. **The United States, China, and Europe lead in quantum, though each draws strength from different areas.** All three have strong human capital and substantial economic resources; each has invested over $9 billion U.S. dollars in quantum technologies, while all other countries remain at or below $3 billion U.S. dollars.[103] China's funding in quantum is primarily fueled by public investment. In the United States, funding is more evenly split between public and private sources, though large firms such as Alphabet and IBM remain the primary contributors. Europe has laid strong foundations for regional quantum growth and drives cohesion through Horizon Europe, the European Union's research and innovation funding program, which now includes the United Kingdom again, as well as Turkey.[104] If levels of funding prefigure future dominance, then the degree of Western unity—particularly the pooling of resources for quantum research, development, and deployment—will largely shape the global balance of quantum power.

**Total Quantum Research Funding by Country or Region**



3. **Although the United States leads in quantum overall, China has a substantial edge in quantum sensing and communications.** Beijing's advantage in quantum sensing and communications is attributable to its prolific research output in these domains and its successful test of quantum communication technology in orbit.[105] To close the U.S.-China gap in applied quantum, the United States and Europe must increase investment in applied research to lay the groundwork for more ambitious projects. This could include developing components for full-stack, multilayer quantum communication networks: technologies that catch and amplify weakened quantum states for long-distance transmission, portable ground units capable of sending and receiving entangled photons from satellites, and atmospheric-resilient networks designed to preserve quantum coherence despite interference from weather or light conditions.[106]

## Additional Findings

- **The United Kingdom, Germany, Canada, France, and Japan each have roughly half the strength of the United States and China in quantum, but collectively they are well-positioned to influence the future of the field in meaningful ways.** These countries share a similar profile: they are strong in quantum security, global governance, and domestic policy, but relatively weaker in terms of economic resources and human capital. They are also democracies integrated into the U.S. alliance architecture, with similar domestic institutions and strong, interlinked academic networks. These shared strengths position them to develop joint quantum infrastructure and shape technical standards for deploying quantum technologies. But to truly lead in quantum, these countries need more than just alliances and partnerships—they must carve out niches that make them indispensable to future quantum technologies and supply chains.
- **Economic resources, quantum sensing, and quantum communications show the widest disparities, underscoring that these areas are the main barriers to building a robust national quantum base.** There is relatively little variation across countries in the pillars tracking engagement in global and domestic quantum policy. By contrast, economic resources, quantum sensing, and quantum communications vary widely across countries, showing how difficult it is for governments to develop or acquire these foundational elements of a viable quantum ecosystem. Indeed, there are very few countries that have amassed long-term public and private investment, high-quality research laboratories and programs, indigenously conducted foundational experiments, or developed prototypes of next-generation quantum systems. If states want to improve their quantum standing by spurring domestic growth, they need to develop and execute multilayered strategies built on a mixed assortment of policy tools: straightforward regulatory roadmaps, subsidies and tax credits for private firms, fast-tracked grants, and direct public investment in areas of core research and development.
- **France, Germany, the Netherlands, and the United Kingdom stand out for their highly collaborative quantum ecosystems.** These countries are active participants in multilateral quantum research and development efforts such as the European Quantum Flagship, the International Council of Quantum Industry Associations, the Entanglement Exchange, and QuantERA. Given how nascent quantum technologies are, active participation in such organizations is especially critical. At this early stage, no single country possesses the full range of capabilities needed to achieve major breakthroughs independently. Collaborative research enables scientists to pool resources, compare findings, and accelerate progress across diverse subfields. The ability to engage in open,

sustained scientific exchange will remain one of the most important accelerators of innovation as countries work to create practical and commercially viable quantum systems.

# Annex

## Choice of Indicators

We evaluated each country's performance in AI, biotechnology, semiconductors, space, and quantum using 8-10 key dimensions called "pillars." These pillars measure national proficiency across fundamental cross-sector factors and sector-specific strengths. In some cases, pillars are the summary of two sub-metrics. In these cases, the score of the pillar is given by the aggregation of the scores of the different sub-metrics. Our assessment framework uses two types of pillars:

1. Fundamental Cross-Sector Pillars:
    - **a. Economic Resources** measure the total scale of funding and revenue relevant to the technology sector. This includes private investments and public funding in absolute U.S. dollar amounts (rather than as percentages of GDP) to capture actual capacity rather than relative intensity.
    - **b. Human Capital** quantifies the size and expertise of the specialized workforce and research community relevant to the technology sector, using metrics such as high-impact publications, research and development personnel counts, patents, and agency staff across the technology sector.
    - **c. Security** measures national resilience and defensive capabilities relative to the technology sector in question.
    - **d. Regulatory** evaluates the maturity and comprehensiveness of legal and policy structures governing the technology sector, including national strategies, industry-specific laws, approval processes, and safety standards.
    - **e. Global Player** measures a country's leadership in each technology through national participation in multilateral forums, international organizations, norm-setting bodies, and major cross-national initiatives.
2. Sector-Specific Pillars:
    - Also included were three to five additional pillars addressing unique characteristics of the technology sector relevant to global power. For example, to analyze countries' advancements in AI, three additional pillars specific to AI were included: **Algorithms**, **Computing Power**, and **Data**.

## Data Collection and Processing

After making a determination on the relevant indicators to target, data points for the selected 25 countries were collected. The data sources encompass reputable international organizations, governmental reports, academic literature, and industry databases to ensure reliability, diversity, and comprehensiveness. The Index relies, in part, on data collected by the following organizations:

- Australian Strategic Policy Institute
- Bloomberg Intelligence
- Center for Security and Emerging Technology
- Centre for Finance, Technology and Entrepreneurship
- Canadian Institute for Advanced Research
- Comparitech
- European Federation of Pharmaceutical Industries and Associations
- Genetic Literacy Project
- International Service for the Acquisition of Agri-biotech Applications
- International Telecommunication Union
- Jonathan McDowell's 2023 Space Activities Report
- McKinsey & Company
- Nuclear Threat Initiative
- Organization for Economic Cooperation and Development
- Portulans Institute
- Union of Concerned Scientists
- United Nations
- The Quantum Insider
- Space Capital
- Stanford Institute for Human-Centered Artificial Intelligence 2024 Artificial Intelligence Index Report
- TOP500
- World Bank
- World Intellectual Property Organization

Given limitations in publicly available data and the iterative nature of this Index, the data presented does not represent a conclusive ranking of countries across the selected technology sectors; rather, it is a framework to better understand critical and emerging technologies in a cross-national context. Indeed, constructing the Critical and Emerging Technology Index required interpretive decisions about which data to include and how to weigh them. Its accuracy is contingent on the quality and timeliness of underlying sources. For the analysis in this report, weights were assigned to each pillar to reflect their relative importance in determining the nations' capability in a specific technology. The assignment of weights to pillars is informed by empirical evidence, the academic literature, data quality, and—when possible—expert consultations.

At the time of publication, the Index primarily uses data from 2023 or, where unavailable, the most recent publicly available data. When there was no publicly available data, multiple regression imputation was used; by identifying and using variables such as GDP, GDP per capita, and population with the highest explanatory power, this approach generated notional scores that serve as estimates of the missing values.

To make results directly comparable across pillars, sectors, and countries, only positive raw metrics were selected, ensuring that "more" always means "better." The data is then normalized using the formula:

$$\text{NormScore}_{c,m} = \frac{D_{c,m} - \min_c(D_{c,m})}{\max_c(D_{c,m}) - \min_c(D_{c,m})}$$

- $\text{NormScore}_{c,m}$ is the normalized (0–1) value for country *c* on metric *m*.
- *m* represents the individual metrics (or sub-metrics) that make up a pillar.
- $D_{c,m}$ is the direction-corrected raw data for country *c* on metric *m*.
- $\min_c(D_{c,i})$ is the lowest value of $D_{c,m}$ of the metric *m* across all countries in the sector.
- $\max_c(D_{c,i})$ is the highest value of $D_{c,m}$ of the metric *m* across all countries in the sector.

Consider the following hypothetical example. The Australian Strategic Policy Institute's Critical Technology Tracker shows that a hypothetical country has 100 "quality" publications in biological manufacturing, 200 in genomic sequencing, 150 in novel antibiotics, 50 in nuclear medicine, and 250 in synthetic biology—an average of 150 publications across those five fields. And as reported by the World Intellectual Property Organization's Intellectual Property Statistics Data Center, the country has 10,000 employees in the top 2,500 pharmaceutical and biotechnology firms. Across all countries, the number of average publications runs from 0 (worst) to 2374.1 (best), so the country's normalized score for publications would be approximately 0.063 (150 ÷ 2,374.1). The employee counts for countries run from 0 to 814,408, so the Country's normalized employee score would be approximately 0.012 (10,000 ÷ 814,408). The average of those two values would be approximately 0.038 ([0.063 + 0.012] ÷ 2). Finally, rescaling that average on a scale of zero to one, where the lowest score is zero and the highest is 0.93, would yield a Biotechnology Human Capital pillar score of approximately 0.041.

Following this, the pillar scores are scaled up by a factor of 100 and then aggregated with the corresponding weights assigned to each pillar, resulting in an overall sector score for each country:

$$\text{SectorScore}_{c,s} = 100 \times \sum_{p=1}^{P_s} \text{PillarWeight}_{p,s}\,\text{NormScore}_{c,p}\,, \qquad \sum_{p=1}^{P_s} \text{PillarWeight}_{p,s} = 1$$

- $\text{SectorScore}_{c,s}$ is the sector score for country *c* in sector *s*.
- $P_s$ is the number of pillars in sector *s*.
- $\text{PillarWeight}_{p,s}$ is the weight assigned to pillar *p* in sector *s* (all the pillar weights in a sector add up to 100%). Here, *p* runs over the pillars within sector *s*.
- $\text{NormScore}_{c,p}$ is the normalized (0–1) value for country *c* on pillar *p*.

To illustrate this, imagine a country with these normalized scores in the AI sector: Global Player at (0.54), Human Capital and Accuracy of Top Models (both 0.07), Computing Power (0.06), Data (0.05), Regulatory (0.04), Economic Resources (0.03), and Algorithms (0.02). The Economic Resources pillar is weighted at 20%, Human Capital at 20%, Global Player at 2.5%, Regulatory at 2.5%, Computing Power at 15%, Algorithms 15%, Data at 15%, and Accuracy of Top Models at 10%. Multiplying each score by its weight and the scaling factor of 100 (0.03 × 0.20 × 100, 0.07 × 0.20 × 100, 0.54 × 0.025 × 100, 0.04 × 0.025 × 100, 0.06 × 0.15 × 100, 0.02 × 0.15 × 100, 0.05 × 0.15 × 100, and 0.07 × 0.10 × 100) and summing the products would yield a sector score of approximately 6.10 for the country.

A final weighted sum of the five sector scores produces the composite Critical and Emerging Technologies Index:

$$\text{IndexScore}_c = \sum_{s=1}^{5} \text{SectorWeight}_s \, \text{SectorScore}_{c,s} \,, \qquad \sum_{s=1}^{5} \text{SectorWeight}_s = 1$$

- $\text{IndexScore}_c$ is the overall Index score for country *c* across all sectors.
- $\text{SectorWeight}_s$ is the weight assigned to sector *s* (all the sector weights add up to 100%).
- $\text{SectorScore}_{c,s}$ is the sector score for country *c* in sector *s*.

For example, imagine a hypothetical country with scaled sector scores of 3.75 for Artificial Intelligence, 5.00 for Biotechnology, 8.20 for Semiconductors, 4.50 for Space, and 3.70 for Quantum. Applying sector weights of 25% for AI, 20% for Biotechnology, 35% for Semiconductors, 15% for Space, and 5% for Quantum would result in weighted scores of 0.9375 for AI, 1.00 for Biotechnology, 2.87 for Semiconductors, 0.675 for Space, and 0.185 for Quantum. Summing these values would yield a final Index score of approximately 5.67 for the country.

One common challenge when building an Index is multicollinearity—highly correlated independent variables that can compromise a regression model's predictive accuracy. For this project, many of the indicators making up the composite scores have a strong correlation with GDP per capita. This correlation, however, reflects the close relationship between economic strength and technological capability. The linkage between economic strength and technological capability is well-documented in the international relations literature.[107] For instance, one recent study found that the outcomes of great power conflicts over the past two centuries were better predicted by GDP and GDP per capita compared to GDP alone or by traditional measures such as the Composite Index of National Capability. To minimize redundancy, indicators were selected to reflect distinct dimensions of technological capacity.

## Artificial Intelligence Metrics Overview as of May 2025

| Pillar | Weight | Explanation and Sub-metrics | Source(s) |
|---|---|---|---|
| Economic Resources | 20% | Captures the financial resources of a nation dedicated to furthering AI capabilities.<br><br>Measured using each country's private sector funding in AI. | Organization for Economic Co-operation and Development AI Policy Observatory, "Live data."<br><br>National Bureau of Economic Research, "Government as Venture Capitalists in AI." |
| Human Capital | 20% | Captures the AI-specific skills, knowledge, and talent to which a nation has access.<br><br>Measured using each country's number of AI publications. | Organization for Economic Co-operation and Development AI Policy Observatory, "Live data."<br><br>Australian Strategic Policy Institute, "Critical Technology Tracker." |

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| Algorithms | 15% | Captures the demonstrated capability of a nation to develop cutting-edge Machine-Learning algorithms.<br><br>Measured using each country's number of notable machine-learning models. | Stanford Institute for Human-Centered Artificial Intelligence, *AI Index Report* (2024). |
| Computing Power | 15% | Captures the demonstrated ability of a nation to build and access compute capabilities.<br><br>Measured using each country's number of ranked supercomputers. | TOP500, "List Statistics."<br><br>Canadian Institute for Advanced Research, "A Quantum Revolution: Report on Global Policies for Quantum Technology." |
| Data | 15% | Captures the capacity of a nation to access a pool of quality data needed to train and adjust AI systems.<br><br>Measured using each country's number of Internet users and volume of broadband per capita. | CIA World Factbook, "Internet users Comparison."<br><br>Statista, "Number of internet users in selected countries."<br><br>World Bank Open Data, "Fixed broadband subscriptions (per 100 people)." |
| Accuracy of Top Models | 10% | Captures the ability of a nation to develop high-performing AI language models.<br><br>Measured using the aggregate of mean win-rate scores for each country's top AI models (mean win-rate denotes the proportion of head-to-head comparisons in which an AI model scores better than another across multiple evaluation scenarios). | Stanford Center for Research on Foundation Models, "Holistic Evaluation of Language Models (HELM) Lite." |
| Global Player | 2.5% | Captures the extent to which a nation is engaged and functions as a leader on the global AI stage in the form of key international partnerships and norm-setting efforts.<br><br>Measured using country involvement in international AI summits, commitments to prominent safety guidelines, and explicit leadership role in prominent global initiatives. | Global Partnership on Artificial Intelligence.<br><br>*The Bletchley Declaration by Countries Attending the AI Safety Summit, 1-2 November 2023*.<br><br>National Cyber Security Centre, *Guidelines for secure AI system development*.<br><br>Organization for Economic Co-operation and Development AI Policy Observatory, "National AI policies & strategies." |
| Regulatory | 2.5% | Captures the extent to which a nation has regulatory and legal frameworks in place to foster innovation and progress in the AI industry.<br><br>Measured using each country's number of AI-related bills passed into law from 2016 to 2023. | Stanford Institute for Human-Centered Artificial Intelligence, *AI Index Report* (2024).<br><br>Chambers and Partners, "Artificial Intelligence 2023 Taiwan." |

Measuring economic resources for AI by counting up Venture Capital investment in AI in 2023 posed a problem for China, as private investment in AI is supplemented by government-guided funds, normally steered by government bodies but partially funded by outside funders. Some of those funders are state-owned enterprises, blurring the line between public and private.[108]

The Organisation for Economic Co-operation and Development AI Policy Observatory's live data page still proved to be the best all-around resource for private AI investment. Alternative sources were also considered. For instance, CB Insights' *State of AI 2023 Report* included data on closed deals only and excluded contingent funding, debt, buyouts, consolidations, recaps, or non-equity government funding, and likely underestimated Chinese AI funding.[109] Pitchbook had two separate reports tracking venture capital deals in the United States and China that also likely underestimated Chinese funding, though not by as much as CB Insights' report.[110] Stanford University's 2024 Artificial Intelligence Index Report, which tracks deals involving AI companies reported on Capital IQ and Crunchbase datasets, unfortunately, does not track government-guided funds.[111]

To accurately reflect China's AI funding while not excluding government-guided funds, the Index still uses the Organisation for Economic Co-operation and Development AI Policy Observatory's figure for AI venture capital funding in China but adds onto it the sum of government-guided funds for AI in 2023 (a relatively small total of $2.16 billion U.S. dollars).[112] Other assessments of China's AI funding have used similar sources.[113] Despite signs of expanding AI funding opportunities in China—such as in Zhejiang province, home to the notable AI startups known as the "Six Little Dragons"—various sources using different methodologies confirm that the United States still holds a sizable lead over China in net economic resources allocated to AI.[114]

The Index measures human capital through publication counts, but this is an imperfect proxy for it. Publications do not fully capture workforce quality or practical expertise, as research papers vary widely in relative impact and relevance. More importantly, breakthrough AI developments are increasingly happening outside universities—for instance, in startups and corporate labs. Another important consideration is the lack of publicly available data on national computing capacity relevant to AI development. The Index uses Top500 supercomputer rankings as a substitute, yet these counts overlook total computing resources and AI-specific compute capacity. Estimates of countries' total compute or compute concentrated in substantial clusters may be more useful for assessing proximity to artificial general intelligence. Unfortunately, most of these estimates concentrate on just the United States and China. If more data on compute becomes available for other countries, future iterations of this Index may not need to rely on supercomputers as a proxy for computing power.[115]

## Biotechnology Metrics Overview as of May 2025

| Pillar | Weight | Explanation and Sub-metrics | Source(s) |
|---|---|---|---|
| Human Capital | 25% | Captures the quality of general biotechnology-related research in a nation and the quantity of researchers available.<br><br>Measured using each country's employee count in the 'top' 2,500 research and development companies in pharmaceuticals and biotechnology, along with the average number of 'quality' publications across biological manufacturing, genomic sequencing and analysis, novel antibiotics and retrovirals, nuclear medicine and radiotherapy, and synthetic biology (based on H-index scores and the share of highly cited work). | Australian Strategic Policy Institute, "Critical Technology Tracker."<br><br>European Commission, *The 2023 EU Industrial R&D Investment Scoreboard*. |
| Pharmaceutical Production | 20% | Captures the level of pharmaceutical innovation in a nation.<br><br>Measured using each country's number of biological materials patents, biotechnology patent grants, and pharmaceutical patent grants. | World Intellectual Property Organization, "IP Statistic Data Center."<br><br>Organisation for Economic Co-operation and Development, "Data Explorer." |

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| Genetic Engineering | 15% | Captures the level of gene editing innovation in a nation.<br><br>Measured using each country's number of genetic engineering publications and the number of 'notable' milestones in human health, gene drives, and agriculture. | Genetic Literacy Project, "Gene Editing and New Breeding Techniques: Regulations, Ratings and Index."<br><br>Australian Strategic Policy Institute, "Critical Technology Tracker."<br><br>EurekAlert, "Korea University study explores a novel and precise mitochondrial gene editing method."<br><br>Singapore Agency for Science Technology and Research, "Singapore Scientists Develop Novel Gene Editor to Correct Disease-Causing Mutations Into Healthy Versions."<br><br>Anadolu Ajansı, "Turkish doctors spearhead treating 'intractable' genetic diseases."<br><br>Forbes, "You May Find Salt-Tolerant Rice Growing In The Ocean By 2021." |
| Vaccine Research | 15% | Captures the quality of vaccine research and COVID-19 vaccine research, development, and rollout in a nation.<br><br>Measured using the average number of each country's 'quality' vaccine and medical counter-measures publications (based on H-index scores and the share of highly cited work) and the number of COVID-19 vaccines developed or in trials. | Australian Strategic Policy Institute, "Critical Technology Tracker."<br><br>COVID19 Vaccine Tracker, "Approved Vaccines" and "Vaccination Rates, Approvals & Trials by Country." |
| Economic Resources | 10% | Captures the financial resources of a nation dedicated to the biotechnology industry.<br><br>Measured using each country's total public bio-technology research and development funding and private sector funding. | Organisation for Economic Co-operation and Development, "Science, Technology and Innovation Scoreboard."<br><br>Organisation for Economic Co-operation and Development, "Emerging technology indicators." (2024) Bank of Korea, "Gross Domestic Product Estimates for North Korea in 2023."<br><br>Fierce Biotech, "20 years in, Singapore still searches for its biotech success story."<br><br>Taiwan Biotechnology and Pharmaceutical Industries Promotion Office, *2023 Introduction to Biotechnology and Pharmaceutical Industries in Taiwan (R.O.C.)*.<br><br>Strategy&, *Accelerating Saudi Arabia's biotech-nology sector: Four enablers to support a Saudi biotech hub*. |

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| Agricultural Technology | 5% | Captures the level of domestic cultivation and innovation with genetically modified crops in a nation.<br><br>Measured based on whether each country has approved genetically modified crops and whether genetically modified crops have been developed domestically, along with the number of genetically modified crop events approved. | International Service for the Acquisition of Agri-biotech Applications, "Biotech Country Facts and Trends" and "Countries with GM Crop Approvals."<br><br>The Royal Society, "What GM crops are currently being grown and where?"<br><br>Genetic Literacy Project, "Where are GMO crops and animals approved and banned?" and "Russia: Crops / Food."<br><br>U.S. Department of Agriculture Foreign Agricultural Service, "Data and Analysis." |
| Security | 5% | Captures the ability of a nation to prevent, detect, and respond to biological threats.<br><br>Measured using each country's score in the *Global Health Security Index* for the "Prevent," "Detect," and "Respond" categories. | Nuclear Threat Initiative, *Global Health Security Index* (2021). |
| Global Player | 2.5% | Captures the extent to which a nation is a leader or participates in international biotechnology organizations and agreements.<br><br>Measured using each country's membership in the relevant international organizations, as well as by violations of treaty obligations. | World Health Organization.<br><br>Food and Agriculture Organization.<br><br>Cartagena Protocol in Biosafety to the Convention on Biological Diversity.<br><br>United Nations Educational, Scientific and Cultural Organization.<br><br>Pan American Health Organization.<br><br>International Centre for Genetic Engineering and Biotechnology.<br><br>European Medicines Agency.<br><br>African Medicines Regulatory Harmonization's National Medicines Regulatory Authorities.<br><br>Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or other Gases, and of Bacteriological Methods of Warfare.<br><br>U.S. Department of State, *Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments* (2024). |
| Regulatory | 2.5% | Captures the policy environment and ease of biotechnology-related approvals and research in a nation.<br><br>Measured using regulatory ease ratings from the Global Gene Editing Regulation Tracker and Index in agricultural gene editing, somatic human gene therapy, germline gene therapy, and gene drives. | Genetic Literacy Project, "Gene Editing and New Breeding Techniques: Regulations, Ratings and Index."<br><br>The CRISPR Journal, "Human Germline and Heritable Genome Editing: The Global Policy Landscape."<br><br>U.S. Department of Agriculture Foreign Agricultural Service, *Agricultural Biotechnology Annual, Taiwan*. |

For Brazil, Iran, and Ukraine, where reliable public biotechnology funding figures were unavailable, government funding was estimated using two complementary approaches. First, a funding range was calculated using each country's score across all other sectors (e.g., human capital or pharmaceutical production) as predictors of public research and development funding. Second, the imputed ranges were reviewed by subject-matter experts at the Belfer Center, who adjusted them to reflect qualitative knowledge of each country's budgetary priorities and recent announcements. The resulting estimates were then normalized alongside the observed data for all 25 countries, ensuring that these three cases remained fully comparable without unduly stretching the scale of their economic resources.

## Semiconductors Metrics Overview as of May 2025

| Pillar | Weight | Explanation and Sub-metrics | Source(s) |
|---|---|---|---|
| Chip Design and Tools | 32.5% | Captures a nation's ability to architect and define next-generation chips.<br><br>Measured using each country's design market share in Logic; Discrete, Analog, and Other; Memory; Electronic Design Automation; and Core IP categories. | Boston Consulting Group and the Semiconductor Industry Association, *Emerging Resilience in the Semiconductor Supply Chain*.<br><br>WireScreen, "The Top Companies Behind the Semiconductor Supply Chain."<br><br>Dialog Semiconductor, *Innovation for a connected world*.<br><br>Business Insider, "Graphcore, which wants to be an AI chip rival to Nvidia, has shut offices and needs more investor cash."<br><br>Alphawave Semi, "Audited Results for the Year Ended 31 December 2022."<br><br>Craft, "Imagination Technologies Financials."<br><br>Pitchbooks, "Dialog," "Graphcore," "Alphawave," "ARM," "Imagination Technologies," and "Siemens EDA."<br><br>Siemens EDA, *Annual Financial Report For Fiscal 2022*.<br><br>Wall Street Journal, "Arm Holdings PLC ADR." |

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| Economic Resources | 20% | Captures the financial resources of a nation available to its semiconductor ecosystem.<br><br>Measured using each country's public funding, along with domestic industry revenues from discrete semiconductors, integrated circuits, optoelectronics, and sensors and actuators. | Australian Strategic Policy Institute, "Critical Technology Tracker" and *Australia's semiconductor manufacturing moonshot: Securing semiconductor talent*.<br><br>Boston Consulting Group and the Semiconductor Industry Association, *Emerging Resilience in the Semiconductor Supply Chain*.<br><br>Statista, "Semiconductors."<br><br>Equal Ocean, "Brazil's Semiconductors Get Boost: Incentives to Draw 30Bn Reais in a Decade."<br><br>Statista, "Aktuelle Subventionen für Halbleiterwerke in Deutschland im Jahr 2023."<br><br>Harrison Pensa, "Canada's place in the semiconductor industry."<br><br>India Briefing, "What is the Semicon India Program and How Does it Work?"<br><br>Bloomberg, "Italy Earmarks $4.4 Billion to Boost Semiconductor Industry."<br><br>The Times of Israel, "Intel clinches $3.2b government grant for $25b chip plant expansion in southern Israel."<br><br>Nippon, "Japan Making Major Investments in its Semiconductor Industry."<br><br>Peterson Institute for International Economics, "The US and Korean CHIPS Acts are spurring investment but at a high cost."<br><br>Statista Market Insights, "Semiconductors."<br><br>CNews, "У властей новый план по развитию российской электроники. Страна потратит сотни миллиардов на техпроцессы 90 и 28 нм."<br><br>Bluesky Education, "How Singapore's Manufacturing Strategy Attracts Major Chip Investment."<br><br>Telecoms, "Spain splashes out €12 billion on chip making."<br><br>U.K. Department for Science, Innovation & Technology, *National semiconductor strategy* (2023).<br><br>Reuters, "White House touts $11 billion US semiconductor R&D program." |

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| Human Capital | 20% | Captures the depth and quality of a nation's semiconductor talent pool.<br><br>Measured using each country's proportion of top 10% publications in advanced integrated circuit design and fabrication by<br><br>'quality' (based on H-index scores and the share of highly cited work) and the number of semi-conductor-related patents. | Australian Strategic Policy Institute, "Critical Technology Tracker."<br><br>World Intellectual Property Organization, "IP Statistics Data Center." |
| Manufacturing and Fabrication | 10% | Captures a country's control over the physical facilities that produce chips.<br><br>Measured using each country's proportion of site capacity for wafer fabrication. | Boston Consulting Group and the Semiconductor Industry Association, *Emerging Resilience in the Semiconductor Supply Chain*.<br><br>WireScreen, "The Top Companies Behind the Semiconductor Supply Chain."<br><br>Bosch, "Bosch aims to accelerate regional and sectoral growth."<br><br>Infineon Technologies, *2022 fiscal year Group performance*.<br><br>Pitchbooks, "Bosch" and "NXP."<br><br>STMicroelectronics, "STMicroelectronics Reports Q4 and FY 2023 Financial Results."<br><br>Nasdaq, "STMicroelectronics N.V. Common Stock (STM) SEC Filings." |
| Equipment | 7.5% | Captures a nation's hold over the specialized machinery that carves transistor patterns.<br><br>Measured using each country's share of the global semiconductor manufacturing-equipment market. | Boston Consulting Group and the Semiconductor Industry Association, *Emerging Resilience in the Semiconductor Supply Chain*. |
| Assembly and Testing | 2.5% | Captures a country's share of back-end semi-conductor operations for turning wafers into finalized chips.<br><br>Measured using each country's proportion of site capacity for assembly, test, and packaging facilities. | Boston Consulting Group and the Semiconductor Industry Association, *Emerging Resilience in the Semiconductor Supply Chain*. |
| Specialized Materials and Wafers | 2.5% | Captures a nation's role upstream in the semi-conductor supply chain through its share of silicon wafers and critical materials.<br><br>Measured using each country's silicon wafer market share and market share in critical sub-systems and semiconductor-related materials. | Boston Consulting Group and the Semiconductor Industry Association, *Emerging Resilience in the Semiconductor Supply Chain*.<br><br>WireScreen, "The Top Companies Behind the Semiconductor Supply Chain."<br><br>Pitchbooks, "Wacker Chemie," "PVA TePla," "Siltronic," "Soitec." |

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| Global Player | 2.5% | Captures the integration of a nation into international semiconductor governance and open-source design ecosystems.<br><br>Measured based on each country's membership in the World Semiconductor Council; inclusion in Quadrilateral Security Dialogue, Chip 4 Alliance, or U.S.-EU Trade and Technology Council initiatives; number of premier RISC-V contributors; and number of strategic RISC-V members. | Nikkei Asia, "Quad to discuss joint investments in chips, critical minerals."<br><br>Global Taiwan Institute, "The "Chip 4 Alliance" and Taiwan–South Korea Relations."<br><br>European Commission, "EU-US Trade and Technology Council."<br><br>RISC-V, "Members." |
| Regulatory | 2.5% | Captures whether a country has an articulated national semiconductor strategy.<br><br>Measured based on whether each country has a dedicated semiconductor industrial policy or program. | Lusha B2B Sales Intelligence, "Semiconductor manufacturing Companies."<br><br>Wall Street Journal, "A Tale of Two Chip Plants: Delayed in U.S., on Time in Japan." |

Human capital was measured using two complementary indicators: the number of top research publications by country of origin, as reported by the Australian Strategic Policy Institute, and semiconductor-related patents from the World Intellectual Property Organization. Each captures a distinct aspect of innovation. Patents—counted by applications, not just grants—serve as strong proxies for innovation due to the cost and effort involved in filing, making them reliable signals for investors.[116] But not all innovation is patentable, particularly tacit knowledge and technical know-how. In such cases, more indirect proxies—such as research quality, measured by the proportion of top publications—are a useful measure.[117]

Patent data measures the number of patents, regardless of the country of origin of filers, filed in each country. This data was taken from the World Intellectual Property Organization's Intellectual Property Statistics Data Center. It did not return entries for North Korea, Iran, Taiwan, Ukraine, or the United Arab Emirates. Taiwan's data was filled in with the Taiwan Ministry of Economic Affairs' 2023 Patent Applications Statistics Report. The number of total patents in 2023 was multiplied by the proportion of Taiwan's patents related to semiconductors from 2022 to produce a final patent number. All of the data, including Taiwan's, are as of 2023, except for Russia (2022), Singapore (2021), and Turkey (2022).[118] An alternative measure of the number of patents received from inventors by country of residence from the Organization for Economic Co-operation and Development's "Patents by WIPO technology domains" dataset was also considered. The metric uses priority year (the year of first filing) and only counts WIPO-administered Patent Cooperation Treaty filings, instead of U.S. Patent and Trademark Office filings or European Patent Office filings, to avoid double-counting. The Organization for Economic Co-operation and Development's 2020 data cutoff date, however, makes it less current than the World Intellectual Property Organization dataset.[119] Including both measures together would have mitigated some of this downside, but it would double-count patent contributions.

Another point of concern was a limitation regarding data collection for Singapore. Observers familiar with Singapore's sizable role in the semiconductor fabrication business may be confused to find it unrepresented in any of the segments of the supply chain. Boston Consulting Group and the Semiconductor Industry Association's 2024 report, the main source for this Index on country-level supply chain data, lumped Singapore, Israel, and all countries outside of the "Big 6" (U.S., China, Japan, Taiwan, South Korea, and the European Union) into one aggregate "Other" category.

Disaggregating the "Other" category to isolate Singapore's market share was not feasible for either the Wafer Fabrication pillar or the Assembly and Testing pillar. For some European countries, disaggregated shares were estimated by identifying relevant firms in WireScreen's map of major semiconductor companies, summing their revenues, and dividing by the total segment value reported in the 2024 Boston Consulting Group and Semiconductor Industry Association report.[120] A similar approach could have been attempted for Singaporean firms in Assembly and Testing.[121] While revenues are an imperfect proxy for industrial capacity, they are useful nonetheless. However, unlike the European countries, Singapore's share of installed and forecasted capacity in these segments is not provided in the report, making its value-added share within the "Other" category unknown. (No Israeli firms appear in the Assembly and Testing category on WireScreen's map, and the single Israeli firm in the Fabrication category faced the same limitation. Had Israel's share of the "Other" category been available, its revenue could have supported a positive score in Manufacturing and Fabrication.)

Another methodological issue complicated efforts to score Singapore's wafer fabrication firms. Many of Singapore's fabrication facilities—which account for roughly 10% of global semiconductor exports by value, according to Growth Lab's Atlas of Economic Complexity—are foreign-owned.[122] As a result, no Singaporean firms appear in the Fabrication category of WireScreen's map. Notably, these facilities are operated by U.S.-headquartered Micron and GlobalFoundries; Taiwan-headquartered Taiwan Semiconductor Manufacturing Company (via an affiliate), United Microelectronics Corporation, and Vanguard International Semiconductor Corporation; Germany's Siltronic AG (with Samsung); and the French-Italian firm STMicroelectronics.[123]

Singaporean firms still account for part of the 7% value-added activity that the 2024 Boston Consulting Group and Semiconductor Industry Association report attributes to "Other" countries. This is because the report define Wafer Fabrication and Assembly and Testing as "based on installed capacity and geographic location" rather than company headquarters.[124] (This 7% figure is lower than the previously cited 10% because Singapore's facilities may be over-utilized relative to the global average.) A detailed review of the firms operating fabrication facilities in Singapore could, in theory, yield installed capacity data aligned with the report's methodology.

However, financial filings from Micron, GlobalFoundries, the Taiwan Semiconductor Manufacturing Company, United Microelectronics Corporation, Vanguard International Semiconductor Corporation, Siltronic AG, and STMicroelectronics show that none report capital expenditures—the metric used in the 2024 Boston Consulting Group and Semiconductor Industry Association report to measure fabrication "installed capacity"—specifically for Singapore.[125] Instead, these firms either did not report Singapore-specific measurements at all (United Microelectronics Corporation) or used ones different from capital expenditures: long-lived assets (Micron and Siltronic AG), non-current assets (GlobalFoundries), or total assets (Vanguard International Semiconductor Corporation).[126] STMicroelectronics comes closest, but its reported physical input metrics do not project out to 2032, as the Boston Consulting Group-Semiconductor Industry Association report does.[127] As a result, even the approach used to estimate European countries' market shares cannot be applied, since Singapore's fabrication capacity is primarily foreign-owned and falls outside the scope of the WireScreen source.

There are trade-offs to using the 2024 Boston Consulting Group and Semiconductor Industry Association report's "geographic location" definition for Wafer Fabrication. On the one hand, defining semiconductor power by the physical location of fabrication facilities aligns with the growing view that economic security requires onshoring. From this perspective, national security involves reducing dependence on foreign manufacturers, which may be unreliable during wartime or other crises. The Taiwan Semiconductor Manufacturing Company's construction of a fabrication facility in Arizona since the passage of the CHIPS and Science Act in 2022 would support this conceptualization of power. Having chips produced in the United States, even by a foreign firm, ensures that a U.S. president could at least secure some domestic chip output if access to Asian producers were cut off.

On the other hand, there are arguments that overseas fabrication facilities should be attributed to the country where the parent company is headquartered, not where the facility is located. The Taiwanese government retains sovereignty over most of the Taiwan Semiconductor Manufacturing Company's assets. For advanced manufacturers such as the Taiwan Semiconductor Manufacturing Company, their most valuable assets are arguably proprietary know-how rather than physical hardware. This is why both the Taiwan Semiconductor Manufacturing Company and the Taiwanese government take extensive measures to protect the intellectual knowledge behind their most advanced chips. Most of the Taiwan Semiconductor Manufacturing Company's cutting-edge facilities remain in Taiwan. To limit knowledge dispersion, protocols are in place to prevent engineers from gaining expertise across too many parts of the manufacturing process. As of February 2025, the Taiwanese government also requires state approval for any of the Taiwan Semiconductor Manufacturing Company's overseas joint ventures.[128] While this Index currently uses the geographic-location definition of semiconductor power for some supply chain segments and the headquarters-based definition for others at its time of release, future editions may benefit from broader data that enables the testing of multiple conceptual approaches.

## Space Metrics Overview as of May 2025

| Pillar | Weight | Explanation and Sub-metrics | Source(s) |
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| Security | 15% | Captures a nation's security and defense capabilities that can be used in space and counter-space warfare.<br><br>Measured based on whether each country possesses or has operated a kinetic anti-satellite system, has or is developing military-grade directed-energy weapons, and has sufficient jamming technologies capable of affecting systems in orbit, along with its total number of military satellites in orbit. | Union of Concerned Scientists, "Satellite Database."<br><br>Secure World Foundation, *Global Counterspace Capabilities: An Open Source Assessment*.<br><br>U.S. Government Accountability Office, "Directed Energy Weapons: DOD Should Focus on Transition Planning."<br><br>The Defense Post, "UK Completes Maiden Trial of DragonFire Laser Energy Weapon."<br><br>The Interpreter, "Rising tensions over outer space – a new diplomatic hot zone."<br><br>Liberty Times Net, "中科院「雷護專案」研發車載雷射砲 小功率版年底前結案."<br><br>Yonhap News Agency, "Arms agency inks deal to locally produce laser designators key to precision strike missions."<br><br>DefenseScoop, "US to give Israel $1.2B for Iron Beam laser weapon."<br><br>Naval Technology, "German Navy completes laser weapon demonstrator trials."<br><br>Breaking Defense, "Countries undergo 'mindset' shift in counterspace capabilities as Israel makes its entry."<br><br>Global Security Review, "Where Next for Australia's Defence Force in Space?"<br><br>War on the Rocks, "Is Military Space-Based Jamming Normal? Some Worry It Is."<br><br>AeroTime, "French Air and Space Force conducts live GPS jamming exercise."<br><br>Indian Defense Analysis, "HimShakti – Indian Army's most lethal Electronic warfare system."<br><br>Arab News, "UN tells Iran to end satellite jamming."<br><br>SMEX, "How Israel's GPS jamming endangers civil aviation and maritime routes."<br><br>SpaceNews, "Space Force satellite jammers would shut down enemy communications temporarily." |

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| Economic Resources | 15% | Captures the financial resources of a nation available to its commercial and defense space ecosystem.<br><br>Measured using each country's public and private sector funding in space. | CIA World Factbook, "Space Programs."<br><br>European Space Agency "ESA budget 2023."<br><br>Foreign Policy Analytics, "The Final Frontier: Outer Space Security & Governance."<br><br>Space Capital, "Space IQ: Space Investment Quarterly."<br><br>ZoomInfo, "Agencia Espacial Brasileira," "China Aerospace Science & Technology Corporation," "Iranian Space Agency Employee Directory," "Saudi Space Commission," "State Space Agency of Ukraine, former National Space Agency of Ukraine," and "The UAE Space Agency."<br><br>Daily NK, "N. Korea completes reorganization of National Aerospace Technology Administration."<br><br>Indian Space Research Organisation, *Annual Report 2022-2023*.<br><br>Statista, "Total number of Roscosmos employees in Russia from 2016 to 2020."<br><br>Government of Canada Canadian Space Agency, "Organization."<br><br>SpaceNews, "The Startup Nation in Space – Israel's Equation for the Space Ecosystem."<br><br>The Korea Times, "Korea's inaugural space agency officially launches."<br><br>Growjo, "Australian Space Agency Revenue and Competitors."<br><br>National Aeronautics and Space Administration, *FY 2020 Annual Performance Report*.<br><br>Rally Recruitment Marketing, "The Surprising Strategy Behind Turkish Aerospace's Early Careers Recruitment Program."<br><br>LinkedIn, "New Zealand Space Agency."<br><br>Apollo.io, "Taiwan Space Agency (TASA)."<br><br>Company, "Office For Space Technology & Industry, Singapore (OSTIN)." |
| Human Capital | 15% | Captures the space-specific skills, knowledge, and talent to which a given nation has access.<br><br>Measured using each country's number of 'quality' research publications on space launch systems (based on H-index scores and the share of highly cited work) and the size of its civilian space agency workforce. | Australian Strategic Policy Institute, "Critical Technology Tracker." |

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| Domestic Launch Capability | 10% | Captures a nation's ability to independently access Earth orbit through domestic launch infrastructure and operations.<br><br>Measured using each country's number of successful orbital launches in 2023 and whether it operates a domestic orbital launch site. | Jonathan McDowell, *Space Activities in 2023*<br><br>EU Funding Overview, "The European Space Agency (ESA)."<br><br>Our World in Data, "Cumulative number of objects launched into space." |
| Positioning, Navigation, and Timing | 10% | Captures the power and capability of positioning, navigation and timing systems owned and operated by a given nation.<br><br>Measured based on whether each country has no satellite navigation capabilities, has the ability to augment a global navigation satellite system, owns a regional satellite navigation capability, owns a global satellite navigation capability, or is developing a high-precision ground-based timing system. | Airports Authority of India, "What is GAGAN?"<br><br>C4ISRNet, "Iran launches 3 satellites amid tensions over ballistic missiles."<br><br>GPS World, "China finishing "High-precision Ground-based Timing System" – a worry for the United States."<br><br>Institute of Navigation, "A Ground-based Regional Augmentation System (GRAS) - The Australian Proposal."<br><br>Geoscience Australia, "Southern Positioning Augmentation Network (SouthPAN)."<br><br>Reuters, "North Korea's first spy satellite is 'alive', can manoeuvre, expert says."<br><br>U.A.E. Space Agency, "Global Navigation Satellite Systems – Augmentation System (GNSSaS)."<br><br>Space Watch Global, "South Korea to Build Its Own Satellite Navigation System by 2034" and "Japan Prepares for GPS Failure with Quasi-Zenith Satellites."<br><br>Defence Turkey, "TRNAV: Türkiye's GPS Independent Positioning and Timing System."<br><br>King Abdullah University of Science and Technology, "KAUST satellite to deliver advanced Earth observation data."<br><br>United Nations Office of Outer Space Affairs, "Global Navigation Satellite Systems (GNSS)." |
| Remote Sensing | 10% | Captures the capability of sensing satellites owned by a given nation.<br><br>Measured using each country's number of optical, radar, and infrared imaging satellites, along with whether the country or a private firm in the country owns or operates a synthetic aperture radar mission. | Union of Concerned Scientists. "Satellite Database."<br><br>EOS Data Analytics, "Types Of Remote Sensing: Technology Changing The World."<br><br>Breaking Defense, "ICEYE to supply Ukraine with SAR satellite imagery via Ukrainian foundation."<br><br>Taiwan Space Agency, "FORMOSAT-9."<br><br>eoPortal, "NeuSAR."<br><br>SatSense, "SatSense and GNS Science Partner to Revolutionise Ground Movement Monitoring in New Zealand." |

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| Science and Exploration | 10% | Captures a nation's demonstrated capabilities in scientific space research and exploration.<br><br>Measured using each country's number of scientific missions in space launched or ongoing, along with an indicator for operating or partnering on a space station. | European Space Agency, "Mission navigator" and "ESA budget 2023."<br><br>National Aeronautics and Space Administration, "NASA Science Missions" and "International Space Station."<br><br>India Department of Space, "Indian Space Science Data Center (ISSDC)."<br><br>Russian Space Web, "Spacecraft."<br><br>Japan Aerospace Exploration Agency, "Launch Records."<br><br>China National Space Administration, "China's Space Program: A 2021 Perspective." |
| Telecommunications | 10% | Captures a nation's capability to transmit data using space-based communications.<br><br>Measured using each country's number of active communications satellites in Low Earth Orbit and Geostationary Earth Orbit. | Union of Concerned Scientists, "Satellite Database." |
| Global Player | 2.5% | Captures a nation's leadership and norms-setting efforts in the international governance of space.<br><br>Measured using each country's involvement and leadership in international partnerships or norm-setting efforts such as the Artemis Accords, the International Lunar Research Station project, and Combined Space Operations Vision 2031. | United Nations Institute for Disarmament Research, "Space Security Portal." |
| Regulatory | 2.5% | Captures whether a nation has an established legal and regulatory framework for activities in space.<br><br>Measured by whether each country has a comprehensive regulatory or legal framework governing government or commercial space operations. | United Nations Office for Outer Space Affairs, "National Space Law."<br><br>New Zealand Space Agency, *National Space Policy*.<br><br>Taiwan Space Agency, "Introduction." |

Because the line between space and defense spending is often unclear, public space budget figures in this Index include associated military activities rather than narrower definitions limited to science and exploration. For Ukraine, the ongoing war made it difficult to estimate current spending, so 2022 data was used. North Korea's budget was estimated as a percentage of its general military expenditures, given publicly released intelligence alleging that Pyongyang utilizes space launch activities largely as a cover for missile and security purposes.[129]

One of the metrics for human capital included the size of the country's space agency. Some publicly available data, however, appeared to include contractors, while others did not. Because it was difficult to determine whether contractors were included, most country data were recorded as found, with comprehensive figures provided when contractors were preferred, when available.

The domestic launch capability pillar reflects a balance of quantity and quality, measured through two primary metrics. The first was compounding the number of successful launches in 2023 and giving those with access to domestic launch sites a multiplier; while there is a positive correlation between owning a launch site and a higher number of launches in a given year, launches may vary from year to year, but access to the launch site continues to be a significant operational and cost advantage to these countries. Therefore, the multiplier is intended to smooth out fluctuations in launch site data by highlighting both the strategic value of site access and the weight of that advantage. Two countries, Australia and Ukraine, possessed a launch site but did not launch anything in 2023; since the launch site multiplier would effectively be multiplied by zero, the total number was substituted with the average number of launches for that year (excluding the number of launches by the United States, Russia, and China, since the number of those launches were proportionally much larger than the rest of the dataset). This adjustment avoided raw scores of zero and did not affect the overall final ranking. In addition, while European Space Agency member states can technically claim all European Space Agency launches, European Space Agency investments are not equally distributed across all member states. Thus, European Space Agency launches were allocated to individual countries based on the percentage of their contribution to the Agency's budget.

The second metric, which tracks the number of objects placed in space, serves as a proxy for launch vehicle quality by capturing the cumulative number of objects launched into space. One successful launch in one nation is not equivalent to one launch in another country. Because launch vehicles vary in payload capacity, it is important to account for this distinction in launch data, as not all launches are equal. This metric also reflects a country's ability to place spacecraft into orbit and reflects a country's legacy in space, thus ensuring that countries with historically active programs but limited 2023 launches are still moderately reflected in the score.

## Quantum Metrics Overview as of May 2025

| Pillar | Weight | Explanation and Sub-metrics | Source(s) |
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| Economic Resources | 20% | Captures the financial resources of a nation available to its quantum technology ecosystem.<br><br>Measured using each country's public funding for quantum research and development, along with private sector funding. | McKinsey Digital, *Steady progress in approaching the quantum advantage*.<br><br>Qureca, "Overview of Quantum Initiatives Worldwide 2023."<br><br>Canadian Institute for Advanced Research, *A Quantum Revolution: Report on Global Policies for Quantum Technology* (2021).<br><br>Statista, "Quantum technology historic public funding as of 2022, by country."<br><br>CB Insights, "Expert Collection on Quantum Tech."<br><br>McKinsey & Company, *Quantum Technology Monitor* (2023).<br><br>Center for Strategic and International Studies, "Innovation Lightbulb: Private Investment in Quantum Technology."<br><br>EPJ Quantum Technology, "Path to European quantum unicorns."<br><br>Council on Foreign Relations, "What Is Quantum Computing?"<br><br>Subcommittee on Quantum Information of the National Science and Technology Council, *National Quantum Initiative Supplement To The President's FY 2023 Budget.*<br><br>Quantum Flagship, "The launch of the Quantum Flagship."<br><br>Sifted, "Funding for quantum startups dropped worldwide in 2023 — but not in EMEA."<br><br>PatentPC, "The Cost of Quantum Computing: How Expensive Is It to Run a Quantum System? (Stats Inside)"<br><br>Tech Monitor, "Intel launches 12-qubit 'Tunnel Falls' quantum chip and reveals plan for $4.6bn Poland factory."<br><br>Analytics Insights, "How Middle Eastern Countries Are Investing in Quantum Tech."<br><br>arXiv, "IBM Quantum Computers: Evolution, Performance, and Future Directions."<br><br>SpinQ, "Superconducting Quantum Computer Price Range: Full Overview."<br><br>Nature, "Quantum supremacy using a programmable superconducting processor." |

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| | | | Philanthropy News Digest, "IBM, Google invest $150 million in U.S.-Japan quantum computing effort."<br><br>Intel, "Intel's New Chip to Advance Silicon Spin Qubit Research for Quantum Computing."<br><br>IBM, "The hardware and software for the era of quantum utility is here."<br><br>Microsoft, "Microsoft unveils Majorana 1, the world's first quantum processor powered by topological qubits."<br><br>Amazon, "Amazon Web Services announces a new quantum computing chip." |
| Human Capital | 15% | Captures the size of the country's quantum technology talent pool.<br><br>Measured using the total number of quantum technology startups and quantum academic groups in each country. | Statista, "Number of quantum sensing startups as of 2022, by country."<br><br>Statista, "Number of quantum communications startups as of 2022, by country."<br><br>Statista, "Number of quantum computing start-ups as of 2022, by country."<br><br>Quantum Computing Report by Global Quantum Intelligence, "Universities" and "Public Companies."<br><br>EduRank, "100 Best universities for Quantum and Particle physics in Brazil."<br><br>Quantum Computing and Information Research Group at Federal University of Pernambuco.<br><br>Quantum Insider, "Groups and Centers."<br><br>Wired, "Alphabet Has a Second, Secretive Quantum Computing Team."<br><br>SpinQ, "23 Leading Quantum Computing Companies Worldwide [2025 List]."<br><br>Builtin, "25 Quantum Computing Companies to Know" and "Top Quantum Computing Companies Hiring Remote Workers."<br><br>Prescient and Strategic Intelligence, "10 Key Players of the Quantum Computing Market."<br><br>The Washington Post, "Can quantum computing change the world? This start-up is betting on it."<br><br>Quantinuum, "Quantinuum Expands Collaboration with JSR to Explore Quantum Computing for Semiconductor Research."<br><br>F6S, "41 top Quantum Computing companies and startups in United States in May 2025."<br><br>TechTarget, "12 companies building quantum computers." |

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| | | | BlueQubit, “10 Leading Quantum Computing Companies at the Forefront.”<br><br>Quantum Zeitgeist, “18 Innovative Public Quantum Computing Companies From Around the Planet.”<br><br>Quantum Insider, “Quantum Computing Companies: A Full 2024 List.”<br><br>Fortune Business Insights, “U.S. Quantum Computing Market Size, Share & Industry Analysis, By Component (Hardware, Software, Services), By Deployment (On-Premise, Cloud), By Application (Machine Learning, Optimization, Biomedical Simulations, Financial Services, Electronic Material Discovery, Others), By End User (Healthcare, Banking, Financial Services and Insurance (BFSI), Automotive, Energy and Utilities, Chemical, Manufacturing, Others), and Country Forecast, 2025-2032.”<br><br>QuestGLT, “Leading Top 10 Quantum Computing Companies in the USA.”<br><br>Stock Analysis, “Quantum Computing Inc. (QUBT).”<br><br>Market.us Scoop, “Quantum Computing Statistics 2025 By Value in Revolutionary Data.”<br><br>Pesquisa Fapesp, “Brazil’s first quantum cryptography network is expected to connect five research institutions.”<br><br>Quantum Computing Group National Laboratory for Scientific Computing.<br><br>Infoptics Quantum Optics and Quantum information group – IF-UFF.<br><br>Te Whai Ao – Dodd-Walls Centre for Photonic and Quantum Technologies.<br><br>University of Auckland, “Quantum Information and Quantum Motion Laboratory.”<br><br>Centre for Theoretical Chemistry and Physics.<br><br>Quantum Technologies Aotearoa.<br><br>National Taiwan University, “Center for Quantum Science and Engineering.”<br><br>National Tsing Hua University, “NTHU Researchers Use One Photon in Developing World’s Smallest Quantum Computer.”<br><br>Center for Quantum Frontiers of Research and Technology, “Who We Are.” |

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| | | | National Central University, ”Quantum Technology Center.”<br><br>National Sun Yat-sen University, “Center for Theoretical and Computational Physics.”<br><br>Quantech at Istanbul Technical University, “Current Research.”<br><br>Koç University, “Quantum Enabling System Technologies (QuEST) Group.”<br><br>Sabanci University, “Quantum Energy Research Group.”<br><br>Sabanci University, “Quantum Transport & Nano Electronics Laboratory.”<br><br>Bilkent University, “Quantum Photonics Lab.”<br><br>Gazi University Photonics Research Center, “About.”<br><br>İzmir Institute of Technology, “Quantum Device Laboratory.”<br><br>Taras Shevchenko National University of Kyiv, “Department of Quantum Field Theory.” |
| Quantum Communications | 15% | Captures the demonstrated capability of a nation to develop quantum communications technology.<br><br>Measured using each country’s number of ‘quality’ research publications on quantum communication (based on H-index scores and the share of highly cited work), along with whether the country has completed a quantum key distribution experiment and whether the country has a quantum communication satellite. | Australian Strategic Policy Institute, “Critical Technology Tracker.”<br><br>Government of Canada, “Quantum Encryption and Science Satellite (QEYSSat).”<br><br>Forbes, “The Quantum Space Race Is Here.”<br><br>SpaceTech Asia, “Japan demos world’s 1st instance of quantum communication with a microsatellite.”<br><br>IOT World Today, “Quantum Tech Offers Resilient Alternative to GPS.”<br><br>SpaceNews, “Quantum Space reveals plan for Scout-1 satellite and Sentry mission.” |

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| Quantum Computing | 15% | Captures the demonstrated capability of a nation to develop quantum computing technology.<br><br>Measured using each country's number of 'quality' research publications on quantum computing and quantum cryptography (based on H-index scores and the share of highly cited work), along with whether the country has developed a quantum computer. | Australian Strategic Policy Institute, "Critical Technology Tracker."<br><br>Australian Government Department of Industry, Science and Resources, "Leading quantum company chooses Australia as site for its groundbreaking utility scale quantum computer."<br><br>IOT World Today, "India Launches Quantum Technologies Long-Term Roadmap."<br><br>Quantum Insider, "South Korea Sets Stage for Technological Revolution with Quantum Computing Initiatives."<br><br>The National, "Aramco launches first quantum computer in Saudi Arabia."<br><br>The Straits Times, "S'pore adds another $300m in investment to develop quantum computers, talent pool."<br><br>ICEX- Invest in Spain, "Spain selected to host one of Europe's first quantum computers thanks to the Quantum Spain programme promoted by the Government of Spain." |
| Quantum Sensing | 15% | Captures the demonstrated capability of a nation to develop quantum sensing technology.<br><br>Measured using each country's number of 'quality' research publications on quantum sensors (based on H-index scores and the share of highly cited work). | Australian Strategic Policy Institute, "Critical Technology Tracker." |
| Policy Environment | 10% | Captures the extent to which the country has a policy environment that promotes and protects domestic quantum technology research and development.<br><br>Measured using whether the country has a coordinated national quantum strategy or government-led quantum initiatives, the number of policies that promote quantum technology innovation, and whether the country has export controls on its quantum technologies. | Canadian Institute for Advanced Research, *A Quantum Revolution: Report on Global Policies for Quantum Technology* (2021).<br><br>NewScientist, "Multiple nations enact mysterious export controls on quantum computers." |

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| Global Player | 5% | Captures the extent to which a nation is a leader or participates in international quantum technology organizations and agreements.<br><br>Measured using each country's membership in bilateral quantum science agreements and key international organizations. | U.S. National Quantum Initiative, "Enhancing Competitiveness."<br><br>QED-C, "Quantum consortia QIC, QED-C, Q-STAR and QuIC form international council to enable and grow the global quantum industry."<br><br>Entanglement Exchange, "Entanglement Exchange Links Quantum Researchers Across Twelve Nations" and "The Entanglement Exchange Celebrates World Quantum Day and Welcomes the Republic of Korea."<br><br>QuantERA, "Consortium."<br><br>India Department of Science and Technology, "BRICS STI Framework Programme, 3rd BRICS Call 2019."<br><br>Les Maisons du Quantique, "French Quantum Ecosystem in one." |
| Security | 5% | Captures the ability of a nation to utilize quantum technologies for security-related applications.<br><br>Measured using whether there are military or intelligence-led efforts for security applications of quantum technologies and whether the country has research and development in quantum cryptography. | Australian Army Research Centre, "Quantum Technology."<br><br>Quantum Insider, "4 Countries That Began Funding Quantum Initiatives in 2022."<br><br>Government of Canada, "DND/CAF's Quantum Science and Technology Strategy."<br><br>U.S. Department of State, "Military-Civil Fusion and the People's Republic of China."<br><br>Quantum Insider, "French National Quantum Update — March 2024."<br><br>C4ISRNet, "French defense ministry picks start-ups to develop quantum computers."<br><br>QuantERA, *Quantum Technologies: Public Policies in Europe* (2023).<br><br>Quantum Computing Lab, "Germany's Action Plan for Quantum Technologies."<br><br>NoCamels, "$32.5M To Develop Quantum Computing In Israel."<br><br>Nuclear Threat Initiative, "Israel Ministry of Defense."<br><br>Nikkei Asia, "Japan to launch U.S.-inspired defense R&D center with eye on AI."<br><br>Nextgov/FCW, "How the US is going Dutch on quantum research."<br><br>Canadian Institute for Advanced Research, *A Quantum Revolution: Report on Global Policies for Quantum Technology* (2021).<br><br>Yonhap News Agency, "S. Korea opens military quantum computing technology institute." |

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Public funding data was drawn from Qureca's "Overview of Quantum Initiatives Worldwide 2023", which compiled information on each country's quantum investment efforts from national quantum strategies, official budget documents, and government announcements.[130] When countries had quantum funding commitments that spanned over multiple years, only the portion up to 2023 was included. For example, China's quantum initiative allocates $15.3 billion U.S. dollars for 2021-2025, so this was prorated to $9 billion U.S. dollars to only reflect funding from 2021-2023.[131] This approach only provides an estimate of the country's quantum funding through 2023, and it does not account for differences in actual disbursement or program implementation.

Gathering private funding data for Quantum posed a unique challenge compared to the other sectors in the Index because of limited transparency around corporate quantum spending. First, more straightforward venture capital funding for quantum technology startups was compiled using CB Insights' "Expert Collection on Quantum Tech."[132] Then, quantum-related investments by large technology firms (specifically Alphabet, IBM, and Intel) were estimated using information on each firm's publicly released quantum systems as of 2023. These firms report annual research and development expenditures, but they do not specify spending by technological focus. To work around this, quantum investment was instead approximated using third-party cost estimates for developing and operating quantum computers.[133] While imprecise, this method reflects publicly available information on breakthroughs and system releases by large technology firms up to the end of 2023.

In contrast to the other sectors in this Index, human capital for Quantum was measured by estimating the size of each country's quantum technology workforce. This was a direct interpretation of human capital as the size of the talent pool contributing to a country's quantum ecosystem. This approach differed from the other sectors in the Index, which relied on research quality metrics to measure human capital. For quantum, research quality was instead used to measure a country's capabilities in specific quantum technology categories: quantum communications, sensing, and computing.

Two main figures were used to estimate the size of each country's quantum technology talent pool. First, the total number of quantum technology startups headquartered in each country was compiled using Statista.[134] Then, the total number of quantum academic groups in each country was compiled from the Quantum Computing Report's list of universities with quantum computing research groups.[135]

Data limitations remain a challenge for measuring advancement in Quantum, particularly for countries that disclose minimal information about their quantum research and development. Several countries report little publicly available data on funding that a recorded value of zero is more reflective of data opacity than actual absence. While the Index captures what is observable, it likely underrepresents activity in countries where quantum initiatives are housed within opaque institutions, receive off-budget funding, or are considered strategically sensitive. Because of this, some low scores may indicate missing data rather than a true lack of engagement in quantum development.

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11 Semiconductors was rated as a 5 out of 5 in terms of GDP Contribution, yielding 5 × 15% = 0.75; 5 out of 5 in terms of Geopolitical Significance, yielding 5 × 30% = 1.50; 5 out of 5 in terms of Systemic Leverage, yielding 5 × 25% = 1.25; 5 out of 5 in terms of Dual-Use Potential, yielding 5 × 10% = 0.50; 5 out of 5 in terms of Supply-Chain Risk, yielding 5 × 10% = 0.50; and 5 out of 5 in terms of Time to Maturity, yielding 5 × 10% = 0.50, for a raw sum of 5.00. AI was rated as a 3 out of 5 in terms of GDP Contribution, yielding 3 × 15% = 0.45; 4 out of 5 in terms of Geopolitical Significance, yielding 4 × 30% = 1.20; 4 out of 5 in terms of Systemic Leverage, yielding 4 × 25% = 1.00; 4 out of 5 in terms of Dual-Use Potential, yielding 4 × 10% = 0.40; 4 out of 5 in terms of

Supply-Chain Risk, yielding 4 × 10% = 0.40; and 2 out of 5 in terms of Time to Maturity, yielding 2 × 10% = 0.20, for a raw sum of 3.65. Biotechnology was rated as a 4 out of 5 in terms of GDP Contribution, yielding 4 × 15% = 0.60; 3 out of 5 in terms of Geopolitical Significance, yielding 3 × 30% = 0.90; 4 out of 5 in terms of Systemic Leverage, yielding 4 × 25% = 1.00; 2 out of 5 in terms of Dual-Use Potential, yielding 2 × 10% = 0.20; 2 out of 5 in terms of Supply-Chain Risk, yielding 2 × 10% = 0.20; and 3 out of 5 in terms of Time to Maturity, yielding 3 × 10% = 0.30, for a raw sum of 3.20. Space was rated as a 2 out of 5 in terms of GDP Contribution, yielding 2 × 15% = 0.30; 3 out of 5 in terms of Geopolitical Significance, yielding 3 × 30% = 0.90; 2 out of 5 in terms of Systemic Leverage, yielding 2 × 25% = 0.50; 2 out of 5 in terms of Dual-Use Potential, yielding 2 × 10% = 0.20; 2 out of 5 in terms of Supply-Chain Risk, yielding 2 × 10% = 0.20; and 2 out of 5 in terms of Time to Maturity, yielding 2 × 10% = 0.20, for a raw sum of 2.30. Quantum was rated as a 1 out of 5 in terms of GDP Contribution, yielding 1 × 15% = 0.15; 1 out of 5 in terms of Geopolitical Significance, yielding 1 × 30% = 0.30; 1 out of 5 in terms of Systemic Leverage, yielding 1 × 25% = 0.25; 1 out of 5 in terms of Dual-Use Potential, yielding 1 × 10% = 0.10; 1 out of 5 in terms of Supply-Chain Risk, yielding 1 × 10% = 0.10; and 1 out of 5 in terms of Time to Maturity, yielding 1 × 10% = 0.10, for a raw sum of 1.00.

12 The total of raw sums across all sectors is 15.15; dividing each sector's raw sum by 15.15 produces preliminary sector weights of approximately 33.0% for Semiconductors, 24.1% for AI, 21.1% for Biotechnology, 15.2% for Space, and 6.8% for Quantum, which were then rounded to produce the baseline sector weights.

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