TAKSHASHILA INSTITUTION

A Framework for Identifying Critical Technologies

Shambhavi Naik, PhD

Takshashila Discussion Document 2024-08
Version 1.0, May 2024

This discussion document delivers a critical analysis of the Indian space reforms and considers pathways for developing space capabilities from a national interest perspective.

Recommended Citation:
Shambhavi Naik, A Framework for Identifying Critical Technologies, Takshashila Discussion Document 2024-08, May, 2024 The Takshashila Institution.

Executive Summary

In the past few years, several countries such as the United States, Australia, Japan, the EU, and the United Kingdom have announced lists of technologies they deem critical for their national interests. These lists are a public signal of governmental priorities and will potentially shape their policy direction.

Critical technologies include artificial intelligence (AI), quantum, biotechnologies, etc, and the criteria for identifying them as “critical” are national security, economic prosperity, and social cohesion. Yet, even as more such lists become publicly known, there is little clarity on what exactly is a “critical technology” and what governmental action it should elicit. This paper proposes a framework to identify critical technologies and drive further public policy actions from an Indian perspective.

This document has been formatted to be read conveniently on screens with landscape aspect ratios. Please print only if absolutely

Author
Shambhavi is the Chair of the Advanced Biology Programme at the Takshashila Institution. She studies governance of emerging life technologies from an India perspective.

Acknowledgements
The author would like to thank Manoj Kewalramani for his valuable comments and feedback.

Table of Contents

Introduction

In 2020, the United States released an initial list of Critical and Emerging Technologies (CET) via the National Strategy for CETs

[1]. The purposes of formulating this list were to promote the national security base and protect America's technological superiority. In 2021, the White House released an Interim National Security Strategic Guidance, which defined three national security objectives: protect the security of the American people, expand economic prosperity and opportunity, and realise and defend democratic values[2]. This revised prioritisation of objectives resulted in an expansion in the list of CETs that includes supercomputing, gas turbine engine technologies, nuclear energy, artificial intelligence (AI), financial technologies, biotechnology, etc.

Similarly, the UK's Science and Technology Superpower Agenda recognises science and technology as a major driver of prosperity, and power in the country[3]. It also highlights a perceived responsibility to deliver the benefits of science to the global society. The UK identifies AI, engineering biology, future telecommunications, semiconductors, and quantum technologies as critical for the UK[4].

In 2023, the EU recommended 10 technologies — advanced semiconductors, AI, quantum, biotechnologies, advanced connectivity, navigation and digital technologies, advanced sensing technologies, space and propulsion technologies, energy technologies, robotics and autonomous systems, and advanced materials, manufacturing and recycling technologies — as critical for the EU countries to develop risk assessments[5]. In a further advisory, the EU identified of these technologies – semiconductors, AI, quantum, and biotechnologies — as immediate risk areas[6].

Australia imagines critical technologies to balance three aspects of national interest — economic prosperity, national security, and social cohesion. The technology fields include advanced manufacturing and materials, AI, advanced information and communication, quantum, autonomous systems, robotics, positioning, timing and sensing, biotechnologies, and clean energy generation and storage.

Japan defines critical technology as "important technologies in which Japan should maintain superiority and remove vulnerabilities to ensure Japan's security and realize the sound development of the Japanese economy"[7]. In October 2022, the Japanese government identified 20 technologies as critical fields: biotechnology; medical and public health technology; artificial intelligence and machine learning; advanced computing; microprocessor and semiconductor technology; data science, analysis, storage and management; advanced engineering and manufacturing technology; robotics; quantum information science; advanced surveillance, positioning and sensing technology; neurocomputing and brain interface technology; advanced energy and energy storage technology; advanced information, communication and networking technology; cybersecurity; space technology, marine technology; transport technology; hypersonics; chemical, biological, radiation and nuclear technology; and advanced materials science[8].

There is an underlying theme of identifying technologies of potential economic and technological advantage as critical. Most country-wise lists share technologies such as AI, biotechnology, quantum, and semiconductors. Others such as the Australian Strategic Policy Institute (ASPI)'s tracker on critical technologies[9] and a Brookings Institution report on country views on critical technologies in the Indo-Pacific region (Table 1) also highlight similar technologies[10].

	Australia	**Cambodia**	**Indonesia**	**Malaysia**	**Philippines**	**Singapore**	**Vietnam**
AI/ML	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IoT/Smart Grid	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Quantum Computing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cyber-security	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cloud Computing			Yes	Yes	Yes	Yes	Yes
5G/Internet Connectivity	Yes	Yes	Yes	Yes	Yes		
Big Data	Yes	Yes			Yes	Yes	
Smart Cities				Yes	Yes	Yes	
Encryption			Yes	Yes		Yes	
Autonomous Vehicles	Yes				Yes		
SpaceTech/ Rocket Launcher/ Smart Spaces	Yes		Yes				

Table 1: Country views on what are critical technologies

While there seems to be consensus on what technologies should be included as critical technologies, there is no clear policy understanding of what constitutes a critical technology. More important, what policy actions should follow in the identification of a critical technology? This paper explores the evolution of the word critical in public policy and posits that traditional strongholds of innovation such as the US or EU may be using this term to signal domestic priorities in the face of rising powers of innovation in developing countries. The paper then recommends that India's criteria for identifying technology as critical should be more stringent and include specific policy actions.

Evolution of the term "critical" in public policy

The word critical is often used in public policy in the context of minerals and other raw materials. In 1939, the US Congress passed the Strategic and Critical Minerals Act in response to an observed deficiency in natural resources of critical and strategic materials. The foreign dependency on materials was a specific observation made during the preceding World War I period, and the term "critical material" stemmed from the urgency of securing supplies on account of the looming World War II. The policy approach was determined to "decrease and prevent wherever possible a dangerous and costly dependence on foreign nations for supplies of these materials at times of national emergency."

The Act led to clear policy actions, either identification of alternative sources of minerals or stockpiling for use during a crisis. The term "critical minerals" is widely used today to refer to irreplaceable materials such as copper, lithium, and rare earths that necessary for important components of technologies that fuel energy and electronic supplies.

The term "critical" has also been used in documents from defence departments in the context of military technologies that are crucial for national security. In this case, as well, there is a clear deficiency of technology input that can lead to a defined problem, i.e., the inability to participate effectively in war and a threat to national security. As with critical minerals, there are definite policy actions that can be executed to alleviate the deficiency, such as investment in research in such technologies or the acquisition of companies that own such technologies. Table 2 summarises the use of the word "critical" in select public policy contexts.

Term	**Deficiency**	**Threat/Problem**	**Policy Action**
Critical mineral	Minerals for equipment in war effort	Inefficient war effort	Stockpile or find alternative supplies
Critical mineral	Minerals needed for important technologies like clean energy or computing	Impact on lifestyle, and future-readiness	Stockpile, find alternative supplies, set up international partnerships

Critical defense technologies	Critical technologies for defense	Impact on national security	Research investment, technology acquisition
Critical technology	Unclear what is deficient, particularly when it is an emerging technology.	Unclear what would be the exact impact or crisis that the lack of technology would lead to	Risk assessments, investment, protectionism

Table 2: Summary of comparisons of the term critical in public policy contexts

The purpose of creating a list of critical technologies must be to guide government action, either through funding or regulation. These actions are broad; for example, investing in biotechnology could include funding projects, or building infrastructure for a wide spectrum of techniques such as bioprocessing, gene synthesis, etc. The exact action of the state will be contingent on market failures and gaps within existing policy measures. Countries could either support indigenous development of a technology or acquire technologies from elsewhere. However, such actions can be made without explicitly calling them critical. Calling a technology “critical” in a public manner, is thus likely a signal to others of that country’s domestic priorities and likely reflects an internal prioritisation of policy in response to increased international competition.

While it may not be necessary for countries to signal their domestic priorities on an international platform, a framework to identify critical technologies may be useful in guiding national policy. This is particularly true for low-resource countries which may be able to provide support only for a few technologies and therefore need to be fastidious in their prioritization. The next section provides a framework for identifying critical technologies.

Framework for Critical Technology

In a 1994 paper, Bimber and Popper explored the use of critical technology as an organising principle for public policy. They recognised the lack of a definition of critical technology as a potential policy problem and suggested that any definition has to be policy-relevant, discriminating, and reproducible. They analysed four features that may be used as characterising properties of a critical technology: it is state-of-the-art, is necessary but not sufficient for national self-sufficiency, is a rate-determining factor for specific applications, and is generic and pre-competitive. The paper concluded that only the last two features may be relevant as criteria for identifying critical technologies.

In this framework, critical technology is a nascent technology with varied, imagined benefits that may provide certain technological or economic advantages. An important facet of this perceived advantage is the possibility to patent and sequester technological progress and leverage technological supremacy to facilitate and consolidate global power.

The move from using critical from a physical material that is excludable to technology, which is neither pre-defined nor has to be excludable by nature is likely an indicator of countries trying to maintain their competitive edge as technology becomes diffuse and widespread. While creating generic lists, performing risk assessments, and identifying broad investment areas may be of use to developed countries, developing countries with fewer resources for scientific development like India need more stringent criteria to ensure that truly critical technologies get the resources they require for development.

Criteria for Criticality

The term critical indicates a threat to routine operations if the critical component is missing. There are three key conditions that govern criticality:

1. There is an actual or perceived threat
2. The absence of the technology would lead to a gap in responding to the threat

3. There is a market failure that prevents the private sector from addressing the gap.

The presence of a threat, the absence of a solution, and market failure mean that the government identifying a technology as critical would formulate follow-up public policy action to build domestic competency. The policy would be dependent on which of the three criteria needs to be strengthened.

1. There is a perceived or actual threat to national security

Figure1: Dimensions of National Security

A pre-requisite of criticality has to be that a crisis or problem situation would ensue if the critical technology is not appropriated. As seen in previous uses of the word “critical”, the technology should be central to some form of domestic security. In contrast to previous uses, which have been primarily applied in the application of military and defence security, the scope of security has now expanded to account for current geopolitical challenges. For critical technologies, security may include:

A. National military security, including international and domestic.
B. Health security, including nutritional security, sanitation, disease prevention and treatment, pandemic preparedness, and climate change mitigation.
C. Energy security, including securing supplies for India's energy needs
D. Data security, including technology for the protection of personal data including personal identifiers, financial data, and health data.
E. Economic security.

A critical technology must feed into the mitigation of issues related to these security areas. There are three dimensions to assessing a threat to national security — perceived threat, the potential impact of the threat, and potential foreign dependency or loss of economic opportunity because of lack of technology access. Technological advantage is an interesting component in an increasingly competitive world; it has been cited before as a reason for countries to anoint a technology critical, but this dimension has to be assessed with caution. Countries have to study their own position in the ongoing technological race, the cost of development of new technologies, and their potential benefits to evaluate whether the perceived benefit will actually materialise.

2. The absence of the technology would lead to a gap in responding to the threat

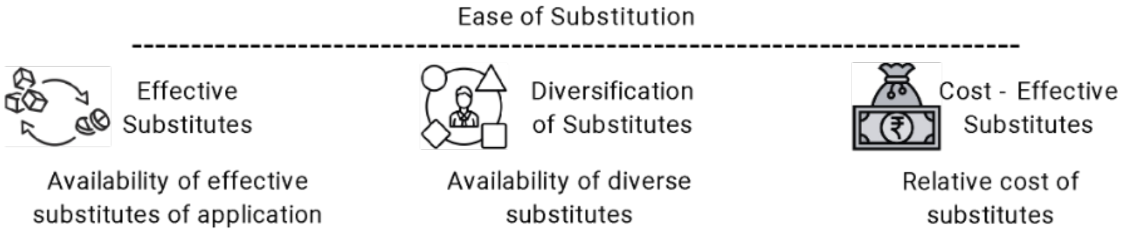

Figure 2: Components of substitutability

The technology should be able to solve a problem or provide a hitherto unseen advantage at costs proportionate to the conferred advantage. Costs in this case include both monetary costs for research and deployment, but also unintended consequences or risks associated with using emerging, untested technologies.

An assessment of available substitutes — the efficiency, diversification and cost — will help estimate this gap. If effective substitutes are available at comparative costs, the technology is not adding value. Conversely, if there is only one effective substitute that is sourced from an adversarial foreign country, the new technology is creating value by removing foreign dependence.

3. There is a market failure that prevents the private sector from addressing the gap.

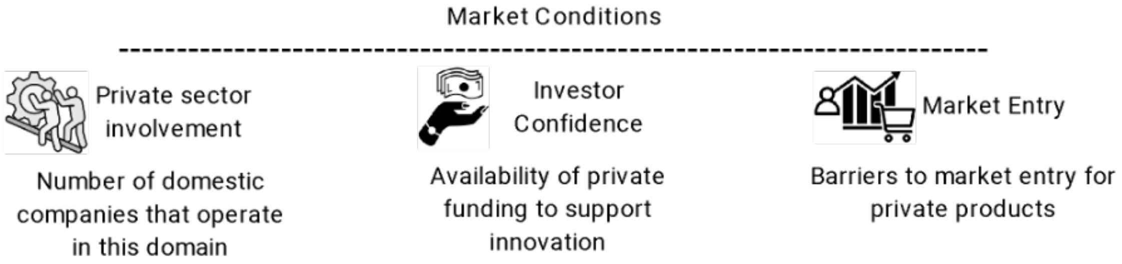

Figure 3: Dimensions of Market Conditions

The identification of a technology as "critical" by the government requires the government to act on its development. Government can take several actions including risk assessments, investment in research, or acquisition of a technology. However, the government should prioritise actions in areas of market failure, instead of spreading its resources across areas where the private sector or civil society can lead. Thus, government action should be driven by the nature of the market failure. For example, the private sector might not be willing to invest in research of an emerging technology with a high chance of failure.

However, if such a technology is essential for India's security, the government should take necessary actions. These actions could include investment in research or collaboration with countries where such technologies are being developed. The assessment of market condition can be made on three dimensions — involvement of domestic private sector companies in the domain, investor confidence in funding the technology, and barriers to market entry.

Examples of assessing technological applications based on this framework

This three-point framework will help prioritise the application of technologies that the Indian government can focus resources on. Below are a few examples of technologies listed as critical, tested using this framework. For a technology to be critical, at least two of three sub-components in each criterion should be marked as red.

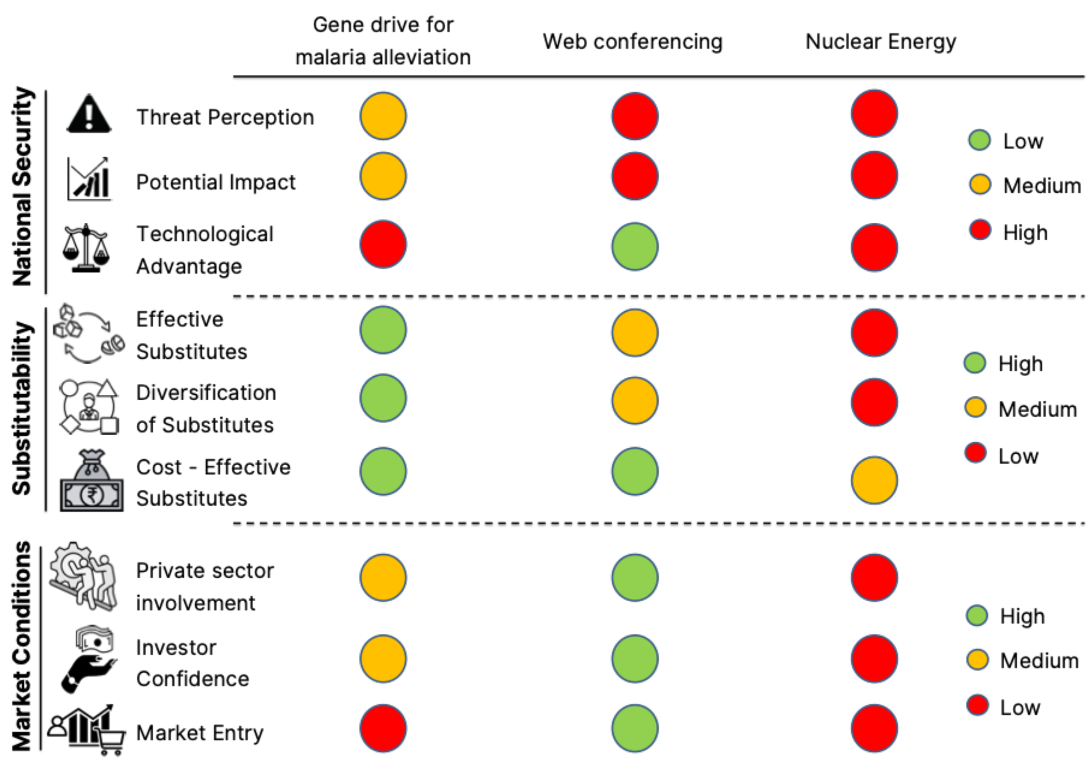

Figure 4: Illustrative examples for using this framework

1. Gene drives for malaria alleviation

Gene drives is an emerging technology that modifies mosquitoes to not carry the malaria-causing plasmodium. This technology can be assessed to be important to health security by preventing vector-borne diseases, beginning with malaria. Few private companies and philanthropic organisations have been involved in funding and operationalising this technology. However, existing technologies such as fumigation, bed nets, and process changes to respond to cases of the disease have been shown to eradicate the disease in Sri Lanka, Uzbekistan, and China. On the other hand, a risk assessment of gene drives demonstrates there are various potential unintended consequences. Hence, the cost of substitution of existing solutions with gene drives is high. Hence gene drive for malaria alleviation is not a critical technology for India.

2. Web conferencing

Web conferencing is a communications tool that is central to various aspects of national security. For example, web conferencing has been extensively used for patient-doctor consultations during and post-COVID, connecting patients even from remote areas to specialist doctors. The absence of these tools would impact health outcomes for these patients. However, web conferencing is available from several private players and there is no further need for policy action from the Government of India to appropriate web conferencing tools. With no clear market failure, web conferencing is not a critical technology for India.

3. Nuclear energy

Nuclear energy is a technology for clean energy that contributes to India's goals for climate change action. As a source of clean energy, it is not a direct comparator to coal. Other clean energy sources such as bio-based energy, wind or solar are still in their nascent stages, and not easily deployable at scale. The high costs of setting up and running nuclear power plants have created barriers for private industry players. Thus, this technology is critical to India's future energy needs, and its delivery has seen market failures. This makes nuclear energy a critical technology requiring governmental interventions.

Conclusion

Creating lists of critical technologies is a good academic exercise to understand domestic priorities. However, a loosely defined critical technology list would lead to the distribution of resources across too many sectors, with each sector receiving marginal attention. It is therefore crucial that developing countries do not simply jump on the bandwagon of creating such lists, but instead develop a framework for identifying and acting on critical technologies.

References

[1] National strategy for critical and emerging technologies. 2020. US White House. https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/10/National-Strategy-for-CET.pdf

[2] Interim National Security Strategic Guidance. 2021, US White House. https://www.whitehouse.gov/wp-content/uploads/2021/03/NSC-1v2.pdf

[3] The UK as a science and technology superpower. 2021. UK Council for Science and Technology. https://www.gov.uk/government/publications/the-uk-as-a-science-and-technology-superpower/the-uk-as-a-science-and-technology-superpower-accessible-html-version-of-letter

[4] The UK Science and Technology Framework. 2024. Department for Science, Innovation and Technology and Prime Minister's Office, 10 Downing Street. https://www.gov.uk/government/publications/uk-science-and-technology-framework/the-uk-science-and-technology-framework#progress-and-next-steps

[5] ANNEX to the Commission Recommendation on critical technology areas for the EU's economic security for further risk assessment with Member States. 2023. European Commission. https://defence-industry-space.ec.europa.eu/system/files/2023-10/C_2023_6689_1_EN_annexe_acte_autonome_part1_v9.pdf

[6] COMMISSION RECOMMENDATION on critical technology areas for the EU's economic security for further risk assessment with Member States. 2023. European Commission. https://defence-industry-space.ec.europa.eu/system/files/2023-10/C_2023_6689_1_EN_ACT_part1_v8.pdf

[7] Joshua P. Meltzer. A critical technology standards metric assessing the development of critical technology standards in the Asia-Pacific. 2022. Global Economy and Development, Brookings. https://www.brookings.edu/wp-content/uploads/2022/09/CTSM-Report-Sep-27_Final.pdf

[8] Ulrich Jochheim. Japan's economic security legislation. 2023. European Parliamentary Research Service https://www.europarl.europa.eu/RegData/etudes/ATAG/2023/751417/EPRS_ATA(2023)751417_EN.pdf

[9] Australian Strategic Policy Institute. Critical Technology Tracker. https://techtracker.aspi.org.au/ Last accessed 12.05.2024.
[10] Joshua P. Meltzer. A critical technology standards metric assessing the development of critical technology standards in the Asia-Pacific. 2022. Global Economy and Development, Brookings. https://www.brookings.edu/wp-content/uploads/2022/09/CTSM-Report-Sep-27_Final.pdf

The Takshashila Institution is an independent centre for research and education in public policy. It is a non-partisan, non-profit organisation that advocates the values of freedom, openness, tolerance, pluralism, and responsible citizenship. It seeks to transform India through better public policies, bridging the governance gap by developing better public servants, civil society leaders, professionals, and informed citizens.

Takshashila creates change by connecting good people, to good ideas and good networks. It produces independent policy research in a number of areas of governance, it grooms civic leaders through its online education programmes and engages in public discourse through its publications and digital media.