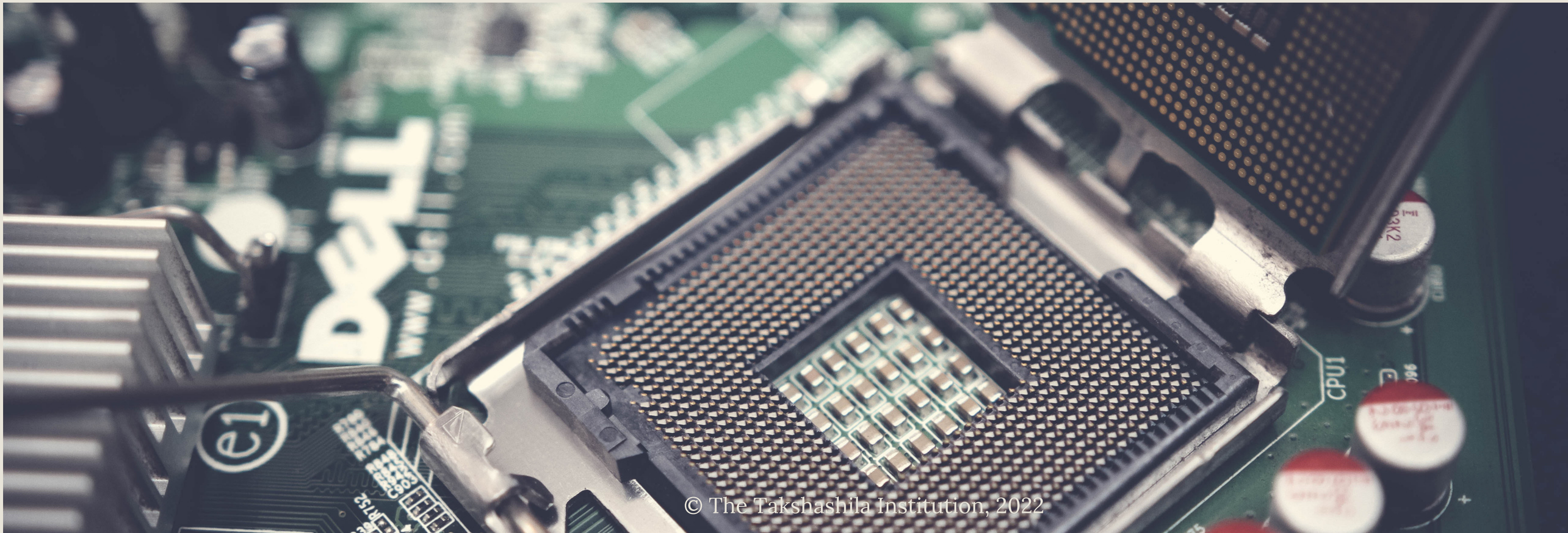
Takshashila Discussion SlideDoc
September 2022
v1.0

Arjun Gargeyas
Samparna Tripathy
Anup Rajput

An AI Hardware Ecosystem in India: A SWOT Analysis



SLIDEDOC OUTLINE

TABLE OF CONTENTS

PAGE

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This document covers the growth of the AI hardware ecosystem around the world and how India can focus on building its domestic capabilities in the domain. It delves into the AI hardware market's global landscape and the domain's economic opportunities. Three recent trends in the semiconductor and AI industries warrant a comprehensive AI hardware policy in India:

- A gradual transition from manufacturing general-purpose to application-specific hardware around the world
- The improved cost-benefit ratio for India to focus on the development of inference-related AI chips
- Emerging alternatives to ARM processor architectures which can handle AI workload better and more efficiently

From an Indian semiconductor and AI perspective, the current ecosystem can be analysed in the following aspects:

- Strengths include semiconductor design expertise and the rise in domestic IP related to AI applications
- Weaknesses are poor R&D ecosystem, supply chain infrastructure and the current investment climate
- Opportunities are the multiplier effects that AI hardware possesses in providing policy solutions for critical sectors
- Threats include the head start that the US and China have gotten in the AI hardware race and prospective regulations on the use of AI in specific applications

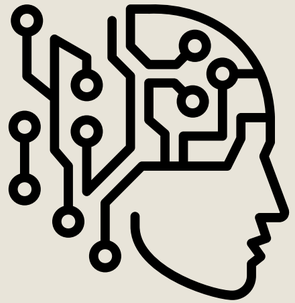
If an AI hardware policy is implemented in the country, policy priorities should include,

- A dedicated trailing edge fab that handles AI inference chip manufacturing
- Supporting and funding open source projects specifically related to AI hardware design
- Expanding existing manufacturing and design policy schemes to include AI hardware development
- International collaboration, especially with the US and Quad, to integrate AI hardware at the multilateral stage

AI AND ITS COMPONENTS

WHAT IS AI?

Artificial intelligence (AI) is defined as a machine's ability to perform cognitive functions associated with human minds, such as perceiving, reasoning, and learning. [1]



Components of AI

Big Data

Processing massive volume of dynamic structured & unstructured datasets

Learning

Upgrading knowledge based on historical patterns, expert input & feedback loops

Reasoning

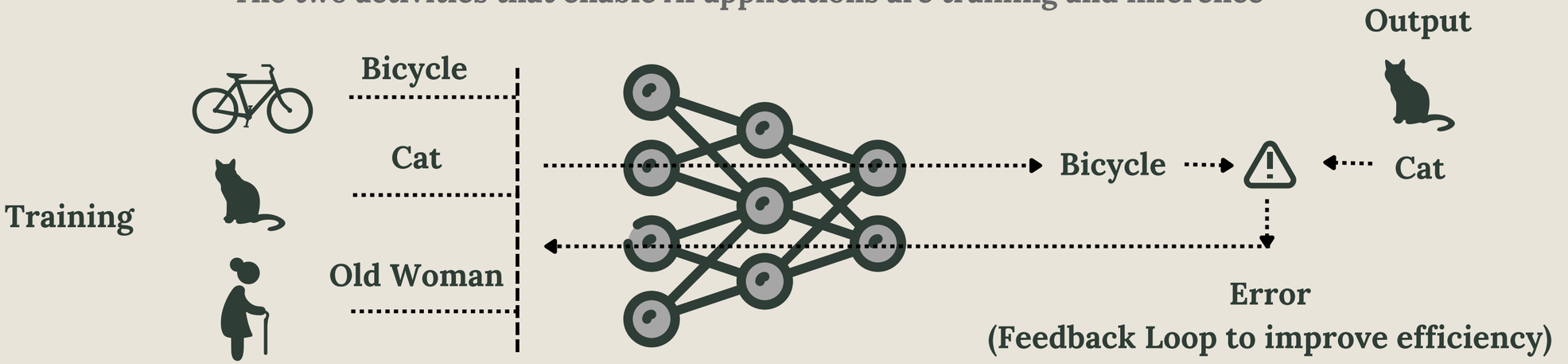
Thinking & drawing inferences based on the context & situation

Problem Solving

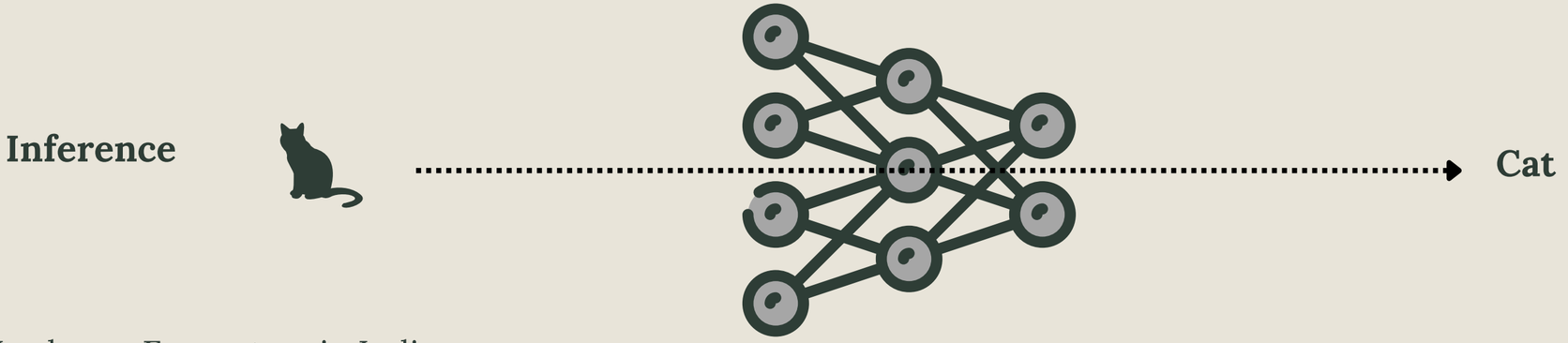
Analyzing & solving complex problems in generic & specific domains

COMPONENTS OF AI ALGORITHMS

The two activities that enable AI applications are training and inference



Ex: In a self-driving car, the training phase would involve exposure to millions of images (of human beings, cats, bicycles) to get the algorithm right. At the inference level, however, algorithms would need to respond faster (no time to contact the cloud) to the situation than to store more data. Hence, AI chips for training & inference vary.



TYPES OF AI HARDWARE

BASED ON ACTIVITY TYPE

	Training	Inference
Intensity & Workload	• Requires massive amounts of data - demands high capacity (memory & computation) • Multiple cycles of going through the data - runs for a long time at full load • Needs power envelope to prevent melting	• Crunches data as it comes in - demands efficiency more than capacity (memory & computation) • Handles the same set of data only once • Requires low power due to low workloads
Extent of Iterative Processes	• Usually trained only once and deployed in multiple phases • No connection is required between the training device and the eventual deployment device	• Needed to run at every place of deployment • Updates itself with firmware upgrades delivered to leaf nodes (endpoints running the inference).
Hardware Specifications	• Requires more heavy-duty hardware • Monopolised by NVIDIA and training GPUs used by crypto miners have slowed down now.	• Cheap and easily available • FPGA makers & Neural accelerators, Chinese chips usually meant for low-cost TVs

BASED ON APPLICATION SPECIFICITY

	Field Programmable Gate Array (FPGA)	Graphic Processing Unit (GPU)	Application Specific Integrated Circuit (ASIC)
Overview	Flexible collection of logic elements and IP blocks that can be configured and changed in the field	Initially designed for graphics; now used in a wide range of computationally intensive applications	Custom integrated circuit optimized for the end application
Strengths	Configurable for specific applications and can be changed after installation; high performance per watt; accommodates massively parallel operation - DSPs, CPUs	Massive processing power for target applications— video processing, image analysis, signal processing	Custom-designed for application with optimum combination of performance and power consumption
Weaknesses	Relatively difficult to program; second-longest development time; poor performance for sequential operations; not good for floating-point operations	High power consumption, not suited to some algorithms; problems must be reformulated to take advantage of parallelism, but API frameworks provide abstraction	Longest development time; high cost; cannot be changed without redesigning the silicon

THE GLOBAL AI HARDWARE LANDSCAPE

THE NEED FOR AI HARDWARE

- The rise of AI applications (from virtual assistants in our homes to facial recognition programs tracking criminals) relies on hardware as a core enabler of innovation.

- As explained before, two activities that enable AI applications are training and inference. [2] The training phase would involve exposure to large data sets to get the algorithm right. At the inference level, however, algorithms would need to respond faster (no time to contact the cloud) to the situation than to store more data.

- This explains the reliance of the training layer on cloud and inference layer on edge/ in-device computing - both of which have varied demands on AI hardware. [3]

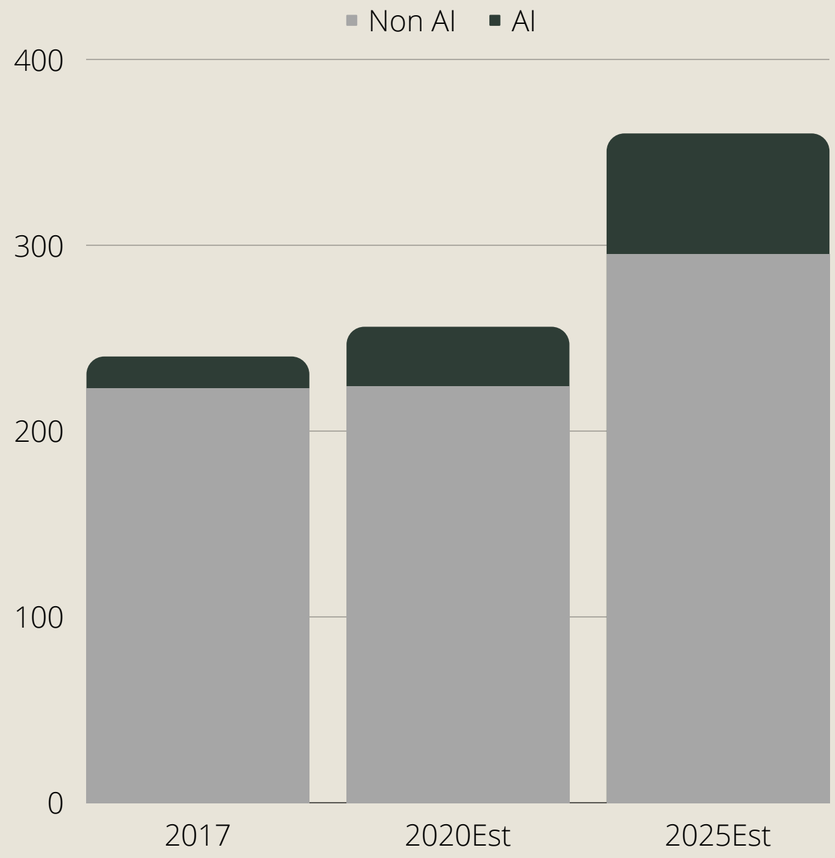
- When developers are trying to improve training and inference, they often encounter roadblocks related to the hardware, which include storage, memory, logic, and networking.

- By providing next-generation accelerator architectures, semiconductor companies could increase computational efficiency or facilitate the transfer of large data sets through memory and storage. Specialised AI hardware can make it much better suited to handling the vast stores of big data that AI applications require.

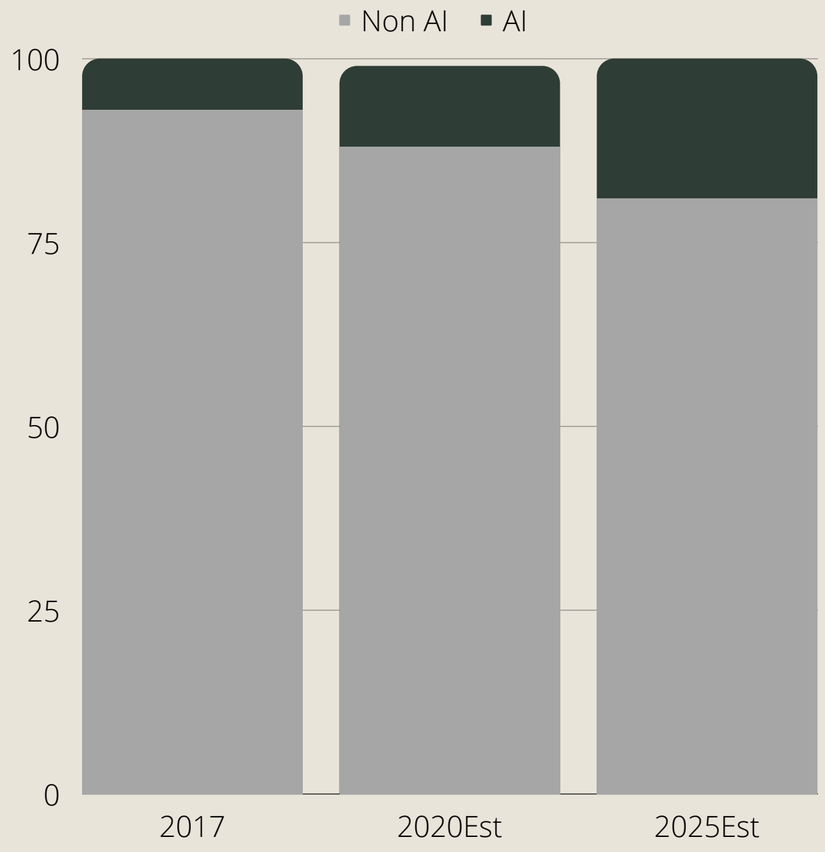
- With hardware serving as a differentiator in AI, semiconductor companies will find greater demand for their existing chips, but they could also profit by developing novel technologies, such as workload-specific AI accelerators.

ECONOMIC SIGNIFICANCE OF AI HARDWARE

AI Semiconductor Total Available Market (in bn USD)



AI Semiconductor Total Available Market %



As per estimates by McKinsey, AI could allow semiconductor companies to capture 40-50 per cent of the total value from the technology stack (the best opportunity to come by in decades). [4]

AI-related semiconductors will showcase a growth of about 18 per cent (compared to 2% of non-AI) annually over the next few years—five times greater than the rate for semiconductors used in non-AI applications.

By 2025, AI-related semiconductors could account for almost 20 per cent of all demand, translating into about $67 billion in revenue. [5]

WHY AN AI HARDWARE POLICY FOR INDIA?

This section analyses the recent global developments in both the semiconductor and AI domains which has made the sector of AI hardware a policy priority field.

Movement Towards Application Specific Chips

- There has been a gradual shift in the semiconductor market, moving from general-purpose to application-specific chipsets. [6] The idea behind an application-driven chip is mainly the ability to perform the same function repeatedly and effectively. AI-enabled hardware fits into the space and is specific to the training algorithm.

- The Ministry of Electronics and Information Technology (MeitY) invited applications under the **Chips to Startup (C2S)** programme for academia, R&D institutions, startups and MSMEs to develop prototypes of application-specific semiconductor chips. [7] It also seeks to train VLSI and embedded systems engineers to design ASICs and FPGAs.

- As per a market research report by Markets and Markets, the demand for AI-related and application-specific semiconductors is valued at $7.6 billion in 2020 and likely to reach $57.8 billion by 2026, at a CAGR of 40.1% during the forecast period. [8]

- The rise in the share of ASICs, GPUs and other applications in the world semiconductor market means that AI hardware is gaining momentum in terms of revenue and importance in the global space. [9] Critical sectors such as space, defence and telecommunications are now on the path to custom hardware with AI capabilities. [10]

Ability to Focus on Inference Chips

- AI-enabled hardware can be categorised into two major types of products based on the AI algorithm components: training and inference chipsets. Regarding cost-benefit ratios, the Indian semiconductor manufacturing dream will benefit from investing in AI inference chips fabs rather than display fabs and other chips.

- There is a cost and requirement gap between the fabrication of AI-enabled chipsets such as training or inference accelerators and normal semiconductor ICs (both leading and trailing edge). [11] The power, data crunching and memory requirements for manufacturing AI training hardware are more than that of AI inference chips. Specific licensed software to design training hardware also increases the costs of production. Hence, AI inference chips look to be the best bet for India when building its ecosystem.

- Unlike trailing and leading-edge nodes, which need large capital investments in advanced computing and AI training chips, India can focus only on large-scale inference chip development and manufacturing to make a mark in the AI hardware domain.

- While AI training hardware has been concentrated with a few firms such as NVIDIA, inference chipsets are low-cost and easily available products designed and manufactured domestically due to their software.

The Rise of Alternatives to Arm

- A crucial aspect of the need to focus on AI hardware is the decline in traditional Arm architecture designs to handle high AI workloads. [12] Though ARM holdings released their v9 microarchitecture focusing on AI (Cortex series) in 2020, it remains a costly, licensed and proprietary-based architecture. [13]

- Since RISC chips deal with a smaller, less complex set of instructions (relegating most work to software instead), more space is left for adding AI capabilities. Amid existing cost pressures on miniaturization and packing more capability on a single chip, alternative architectures (like RISC-V) are preferred for integrating high-level AI algorithms with semiconductor chips. [14]

- RISC-V is growing in terms of acceptance (due to it being open source with zero licence or royalty fees) as well as the maturity of its ecosystem (the rapid development of compilers and verification tools). The Indian government also launched the '**digital RISC-V**' initiative pushes which showcases the tilt towards reducing dependencies on licensed architecture. [15]

- With Arm processor cores less feasible to handle AI algorithm training and inference at an effective level and India pushing towards alternatives such as RISC-V that can benefit AI integration, the focus on AI hardware is imperative currently.

SWOT ANALYSIS

FOR BUILDING INDIA'S AI HARDWARE ECOSYSTEM

It is imperative to understand where India stands in the AI hardware domain. This section elucidates the strengths & weaknesses (factors internal to the ecosystem) and opportunities & threats (factors external to the ecosystem) from both the semiconductor and AI perspectives.

STRENGTHS

THE SEMICONDUCTOR PERSPECTIVE

A THRIVING DESIGN WORKFORCE

- A growing domestic semiconductor design workforce with all significant international semiconductor firms having their design houses in the country. [16]
- Exposed to state-of-the-art design cycles covering AI and ML that can contribute to building training and inference accelerator designs.
- Students are trained in VLSI design through government programmes (Special Manpower Development Programme (SMDP) and Technical Education Quality Improvement Program (TEQIP), with several private institutes offering design courses for upskilling. [17]

EASY ACCESS TO AI HARDWARE MODELS

- There are already available open-source (royalty-free and non-licensable) parallel-computing platforms and application programming interfaces (APIs) to build AI applications on semiconductor chips which can be used to handle AI workloads in hardware. [18]
- A fledgling startup space domestically with firms already having their line of AI hardware products. Firms such as Alpha ICs and QpiAI have dished out their type of instruction set architectures suited for training and inference.

MANUFACTURING AND DESIGN POLICY PRIORITIES

- Recent semiconductor manufacturing policy towards the development of fabrication facilities in the country with upfront fiscal support by the government for both leading and trailing edge nodes (up to 65nm). [19]
- The Indian Semiconductor Mission (ISM), the nodal agency for all semiconductor manufacturing-related schemes, can inspire investor confidence and help kickstart commercial operations for chip manufacturing. [20]
- Design-linked incentive (DLI) scheme was also introduced to focus on India's comparative strength in the semiconductor ecosystem. [21]

THE AI PERSPECTIVE

RISE IN HOMEGROWN IP FOR AI

- India ranked 8th in the world for AI-related patents during 2002-2019, with over 1037 AI patent families. [22]
- A slow and steady rise in the development of indigenous AI applications, with 14% of Indian patents and IP being related to applications compared to the worldwide average of 10%.

AVAILABILITY OF LABOUR AND HUMAN CAPITAL

- A huge talent supply in the form of computer science, electronics and information technology engineering graduates entering the workforce every year. Cutting-edge AI research takes place both at academic and non-academic institutions. [23]
- The launch of the government's AIPortal highlights the strides taken by all AI researchers in the country. The government-supported portal documents all AI-related work across government, academia and start-ups. [24]
- Under the Atal Innovation Mission, the government aims to cultivate researchers and AI scientists for the future.

WEAKNESSES

THE SEMICONDUCTOR PERSPECTIVE

LIMITED DOMESTIC SUPPLY CHAIN INFRASTRUCTURE

- High setup costs (of Electronic Design Automation tool licences) for designing AI hardware proof of concept amid muted investor funding & limited public design infrastructure. This makes costs of production high for start-ups. [25]
- In the absence of fab linkages, the TAT for testing, validation & go to market of AI hardware is too high for domestic players to remain competitive.
- As new AI hardware (training and inference) comes out in the future, firms will end up using advanced nodes below 28nm to provide high speed. Advanced packaging technology also is required to operate AI hardware within the thermal budget. India is nascent on both fronts, i.e. leading-edge node fabs and adoption of advanced packaging.
- State-of-the-art AI hardware requires transistors that require faster cooling. [26] Inadequate availability of large quantities of pure water (~8 million gallons per day), uninterrupted power (~169 MWh), pollution-free environment (controlling for temperature & humidity), logistics, and waste disposal in India are manufacturing bottlenecks.

MEAGRE DOMESTIC DEMAND

- With AI hardware still at a nascent stage of development in the country, there aren't many use cases for such a type of technology currently. Although there is a multitude of potential applications and sectors that require AI hardware, current domestic consumption is very limited.
- Firms now have to focus on exports and the international market for revenue generation. India's current AI hardware quality and output lag behind those of the US and China, making it extremely difficult for firms to compete globally. This can deter and disincentivise up-and-coming players from getting into the field.

THE AI PERSPECTIVE

POOR RESEARCH AND SUPPORTING INFRASTRUCTURE

- Poor faculty, low post-doc fellowship salaries & career tracks in Indian universities discourage scientific AI research in the country. [27] Cross-country collaborative research on AI hardware remains non-existent currently.
- The lack of good quality labelled data sets creates a lack of scale for experimental validation in all AI-related research.
- The limited domestic on-demand computing infrastructure for large experimental AI training creates a higher need for specialised hardware such as GPUs and ASICs. [28]
- Underlying support infra - like 24*7 ACs - for housing GPU clusters are also missing in India's infrastructure.

INVESTMENT AND FUNDING

- Military, public safety, and government applications (including security & biometrics) account for a minuscule proportion (2.6%) of disclosed investment value in Indian AI companies.
- The finance ministry has reportedly approved the expenditure of 1 billion USD for Niti Aayog's proposed AI program (sanctioned to be utilised by 2024-25). [29] Comparatively, China has set aside a budget of 5 billion USD for AI investments, and the US has sanctioned 935 mn USD for non-defence AI + 4 billion USD in defence-related AI.
- India lacks a data protection, ethics & standards framework for AI dissuading the adoption of AI hardware also.

OPPORTUNITIES

THE SEMICONDUCTOR PERSPECTIVE

COMPARATIVE BENEFITS OF AI HARDWARE

- Specialised memory for AI-related hardware has almost 4.5x bandwidth compared to traditional chipsets. [30] The accelerator architecture used in these chips increases computational efficiency and storage, which can benefit a lot of specialised sectors like the military and space.
- The emerging non-volatile (NV) memory market (of which AI hardware is a part and growing at a CAGR of 10.26% till 2025) is slightly costlier to develop but is offset by performance improvement. [31] These memory chips have a higher density, better performance and power consumption than other memory segments, thus making them the future of the memory market.
- Trailing edge nodes are satisfactory for developing and manufacturing AI inference chips. China (firms such as Efinix, Gowin and Shenzhen Pango) manufactures AI hardware (mostly FPGAs) with 55-40 nm node technology which is low-hanging fruit for India looking to set up its first commercial fabrication facility. [32]

THE AI PERSPECTIVE

ROUTE TO CREATING INDIAN SPECIFIC APPLICATIONS

With multiple use cases of artificial intelligence and machine learning cropping up, there is an opportunity to utilise AI-enabled hardware to tackle critical issues specific to India. This includes but is not limited to,

1. **National Language Processing (NLP)** - Considering the linguistic diversity of India, AI-enabled hardware can be used to develop systems catered for the local population to bridge the communication gap. [33] NLP devices can help streamline translations between regional languages and remove linguistic barriers.
2. **Network Security** - With large-scale telecommunications networks and massive public data infrastructure in the country, security and privacy risks are involved. AI hardware can be developed to provide adequate security and protection by analysing and predicting cybersecurity threats. [34]
3. **Computer Vision** - One of the critical applications of AI hardware is developing computer vision models that automate tasks like the human brain. [35] It is a significant factor in the transportation sector for parking occupancy detection, estimating and tracking traffic flow, road condition monitoring, and pedestrian safety, which remain critical areas for policy decisions.

THE AI PERSPECTIVE (CONTINUED)

POLICY SOLUTIONS FOR CRITICAL SECTORS

There is also the ability of AI to provide effective decision making models and systems for some of the critical sectors that need policy solutions in the country. These sectors include but are not limited to,

Healthcare

- The Union government's investment in the healthcare sector has seen an uptick with the Covid-19 pandemic.
- With greater funds and resources from the government side, AI hardware systems can be used to develop better medical imaging technology in govt facilities like CT and MRI scans, and X-ray analyses to improve access and integrate technology into public health. [36]
- AI has also proved itself in specific applications like cancer detection and digital pathology to improve diagnosis, especially with less workforce available in the public sector.

Manufacturing

- With the government launching initiatives (National Manufacturing Policy) to improve the manufacturing sector's contribution to the GDP, there is a clear policy priority to upscale the existing manufacturing infrastructure in the country.
- A recent report by a Hong Kong-based think tank, Natixis, provides extensive details on the market opportunity for India in manufacturing (both labour and capital intensive). [37]
- AI hardware has the potential to introduce efficiency improvement in the sector through streamlining assembly lines in large-scale manufacturing setups and defect detection in sectors such as pharmaceuticals. [38]

THE AI PERSPECTIVE (CONTINUED)

Agriculture

- Around 40% of India's workforce is still in the agriculture sector, contributing just 20% to the country's GDP. The field needs upliftment in terms of utilising technology to improve productivity.
- An Ernst and Young report showcases how India has only tapped into 1% of the global Agri tech market potential with a massive scope to expand. [39] The domestic sector plays home to over 1200 agritech startups employing AI and ML to develop more sustainable alternatives.
- AI hardware has the potential to tackle some major challenges such as pests, insects and plant disease detection, crop monitoring and irrigation management, and livestock health monitoring that can easily improve efficiency and yield. [40]

Military and Defence

- Indigenous defence production and procurement have been pushed forward in the last five years. The Ministry of Defence has also set aside lists of military items specifically for domestic manufacturing. [41]
- At the same time, the 'intelligentisation' of the armed forces is being promoted with improved military technologies.
- AI hardware's role in defence can be categorised but limited to detecting cross-border infiltration, developing lethal autonomous weapons systems (LAWS), monitoring border infrastructure development, and modern military hardware such as drones. [42]
- Hence, with guaranteed procurement by the armed forces, the market and necessity for this technology is an opportunity for Indian firms to get into the field.

THREATS 💣

THE SEMICONDUCTOR AND AI PERSPECTIVE

THE US AND CHINA COMPETITION

- Two of the world's biggest technological powers, the US and China, currently dominate the AI hardware market. [43] The supply chain is currently concentrated in the US due to Electronic Design Automation (EDA) tools licences for designing state-of-the-art AI hardware.
- The GPU market (NVIDIA, AMD) and the FPGA market (Xilinx and Intel) are dominated by US firms. The US also owns the most fabs worldwide, keeping its manufacturing output high.
- China is catching up with the US in terms of using lower-edge nodes to build AI hardware, with its output right behind that of the US.
- Hence, Indian firms will have difficulty carving out a market space for themselves with external dependencies and stiff competition for exports.

LEGISLATIONS AND REGULATIONS ON AI USE

- With the emergence of the ubiquitous use cases of AI, there have been questions about how AI can infringe on the rights of citizens. [44]
- In this case, several legislations have been introduced globally to safeguard one's privacy rights against using AI in certain cases.
- This also raises the potential of the Indian government to introduce new laws that prohibit the use of AI in certain applications or sectors.
- Prospective regulations on the use of AI limit the scope and act as a deterrence factor for the AI hardware industry.

RECOMMENDATIONS

A Trailing Edge Fab for Inference Chips Production

- The government's 'Scheme for setting up Semiconductor Fabs in India' as part of the 2021 semiconductor package provides financial incentives to build fabs from 28-65 nm. [45]

- Trailing edge fabs require less investment and can be set up faster to start production. With trailing edge nodes sufficient for AI hardware production, a 45+ nm fab in the country can be used for the large-scale production of AI inference chips.

- A priority can be a public-private partnership for a trailing edge fab dedicated to handling AI hardware production.

Fund and Support Open Source Projects Related to AI Hardware Design

- With parallel computing design languages dominated by few firms and their proprietary codes, the government can support (along the same lines of RISC-V) open-source projects to design AI training hardware.

- OpenAI's Triton language has been deemed a credible alternative to NVIDIA's CUDA. US's DARPA has also developed Real-Time Machine Learning (RTML) to develop ASICs tailored for running ML operations.

- One such project for the government to focus on could be IISc's ARYABHAT-1 (Analog Reconfigurable Technology And Bias-scalable Hardware for AI Tasks) - a type of chipset especially helpful for AI-based applications – or those that require massive parallel computing operations at high speeds. [46]

Expand Existing Policy Schemes to include AI Hardware

- The government has also initiated schemes such as the ‘Scheme for setting up Compound Semiconductors Facilities’ and ‘Design Linked Incentive (DLI) Scheme’ to build a domestic semiconductor ecosystem. [47] [48]

- Research on compound semiconductors like Gallium Nitride (GaN) and Silicon Carbide (SiC) to integrate AI can be kickstarted as part of the existing scheme.

- The scope of the DLI scheme (especially the deployment-linked incentive aspect) can also be broadened to include parallel computing languages and other design aspects related to AI hardware.

International Collaboration with the US and Quad

- Technology cooperation with the US and other like-minded tech powers remains imperative for India as it will provide access to research on AI training hardware. The recent sanctions by the US government on AI hardware firms preventing exports to China emphasise the need to be on the side of the US if India wants to grow in this space.

- The Quad's 'Semiconductor Supply Chain Initiative' can include AI hardware as part of its collaborative efforts, with a Centre of Excellence (CoE) being set up in one of the Quad countries for AI hardware production.

- Considering the existing head start and advantages that the US and China possess in the AI hardware realm, multilateralism is essential to keep this supply chain independent of China. India can play a role in specialising in a specific part of the AI hardware supply chain with the help of other techno-democratic semiconductor powers ensuring global dependency on its industry.

CONCLUSION

CONCLUSION

With the rise of Artificial Intelligence (AI) and its applications across multiple sectors, there is also the need for better and more efficient computational hardware to handle AI algorithm workload.

The document evaluates the strengths, weaknesses, opportunities and threats from an Indian perspective. From the analysis, we find that India, with its design expertise and rise in AI-related Intellectual Property (IP), has an advantage in the domain. However, we also find that poor R&D, supply chain infrastructure and investment climate might be setbacks. AI hardware having multiplier effects and benefits over the average semiconductor chip can help boost India's hardware manufacturing growth. The existing market concentration with US and China and prospective AI regulations can hamper India's domestic growth capability.

Based on our evaluation, we recommend that a trailing edge fab is sufficient for AI hardware production, which can be prioritised. Another aspect for India would be to support open-source projects related to AI hardware. Finally, international cooperation (especially with the US) remains critical for India to build its AI hardware ecosystem.

Acknowledgements:
The authors would like to thank Pranay Kotasthane for his valuable comments and insights on the document.

REFERENCES

REFERENCES

[1] McCarthy, John. "What is artificial intelligence?." (2007).
http://faculty.otterbein.edu/dstucki/inst4200/whatisai.pdf

[2] Jesús Vergara, "What are 'Training' and 'Inference' in Artificial Intelligence?", Neuroons. Published 22nd January 2021.
https://neuroons.com/what-are-training-and-inference-in-artificial-intelligence/

[3] Intel Team, "Designing AI systems: Fundamentals of AI software and hardware", Venture Beat. Published August 4th 2022.
https://venturebeat.com/business/designing-ai-systems-fundamentals-of-ai-software-and-hardware/

[4] Gaurav Batra, Zach Jacobson, Siddarth Madhav, Andrea Queirolo, and Nick Santhanam, "Artificial-intelligence hardware: New opportunities for semiconductor companies, Mckinsey & Company. Published December 2018.
https://www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/Artificial%20intelligence%20hardware%20New%20opportunities%20for%20semiconductor%20companies/Artificial-intelligence-hardware.ashx

[5] Ibid.

[6] Stephen Watts, "How application-specific integrated circuits are powering the future of IT today", CIO. Published March 8th 2018.
https://www.cio.com/article/228545/how-application-specific-integrated-circuits-are-powering-the-future-of-it-today.html

[7] Press Information Bureau, "MeitY invites applications under the Chips to Startup (C2S) Programme from academia, R&D organisations, startups and MSMEs", Ministry of Electronics & Information Technology, Government of India. Posted 16th January 2022.
https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1790350

[8] "Artificial Intelligence (Chipsets) Market by Technology (Machine learning, Natural Language Processing, Context Aware Computing, Computer Vision), Hardware (Processor, Memory, Network), End-User Industry, and region - Global Forecast to 2026", Markets and Markets. Published September 2020.
https://www.marketsandmarkets.com/Market-Reports/artificial-intelligence-chipset-market-237558655.html

REFERENCES

[9] "Global Application Specific Integrated Circuits Market (ASIC) : Industry Analysis and Forecast 2019-2026 by Product, By Application and By Region.", Maximise Market Research Report. Published September 2019.
https://www.maximizemarketresearch.com/market-report/global-application-specific-integrated-circuits-market-asic/16493/

[10] MIT Schwarzman College of Computing, "New program bolsters innovation in next-generation artificial intelligence hardware",
https://news.mit.edu/2022/new-program-bolsters-innovation-next-generation-artificial-intelligence-hardware-0329[

[11] Sagar Khillar, "Difference Between AI Processor and Normal Processor", DifferenceBetween.net. Published 10th June 2019.
http://www.differencebetween.net/technology/difference-between-ai-processor-and-normal-processor/

[12] Sun Lee, "NVIDIA and the battle for the future of AI chips", WIRED. Published 17th June 2021.
https://www.wired.co.uk/article/nvidia-ai-chips

[13] Jon Porter, "Arm's first new architecture in a decade is designed for security and AI", Published March 30th 2021.
https://www.theverge.com/2021/3/30/22357951/arm-armv9-architecture-security-artificial-intelligence-performance

[14] Jeff Shepards, "RISC-V for artificial intelligence machine learning and embedded systems", Microcontroller Bits. Published December 2nd 2020.
https://www.microcontrollertips.com/risc-v-artificial-intelligence-machine-learning-embedded-systems-faq/

[15] Press Information Bureau, "India launches Digital India RISC-V (DIR-V) program for next generation Microprocessors", Ministry of Electronics and Information Technology, Government of India. Posted 27th April 2022.
https://pib.gov.in/PressReleasePage.aspx?PRID=1820621

[16] "Study on semiconductor design, embedded software and services industry", India Semiconductor Association (ISA). Published April 2011.
https://www.meity.gov.in/writereaddata/files/Semiconductor06April11_020511.pdf

REFERENCES

[17] Shilpa Phadnis and Sujit John, "Why India needs a lot more talent that can craft chips", Gadgets Now by Times of India. Published April 17th 2021.
https://www.gadgetsnow.com/tech-news/why-india-needs-a-lot-more-talent-that-can-craft-chips/articleshow/82115437.cms

[18] Tobias Mann, "Nvidia gets down with low code in AI Enterprise update", The Register. Published 26th July 2022.
https://www.theregister.com/2022/07/26/nvidia_enterprise_ai/

[19] Semiconductors and Display Fab Ecosystem, Ministry of Electronics and Information Technology, Government of India.
https://www.meity.gov.in/esdm/Semiconductors-and-Display-Fab-Ecosystem

[20] Ibid.

[21] India Today Web Desk, "India's semiconductor mission and how it can drive employment", India Today. Published 11th May 2022.
https://www.indiatoday.in/education-today/jobs-and-careers/story/india-s-semiconductor-mission-and-how-it-can-drive-employment-1948191-2022-05-11[

[22] Husanjot Chahal, Sara Abdulla, Jonathan Murdick and Ilya Rahkovsky, "Mapping India's AI Potential", Centre for Security and Emerging Technology (CSET). Published March 2021.
https://cset.georgetown.edu/wp-content/uploads/CSET-Mapping-Indias-AI-Potential-1.pdf

[23] "Number of students enrolled in engineering at an undergraduate level across India in 2020, by discipline", Statista. Published June 2021.
https://www.statista.com/statistics/765482/india-number-of-students-enrolled-in-engineering-stream-by-discipline/

[24] Press Information Bureau, "National AI Portal (INDIAai.gov.in) celebrates its second anniversary", Ministry of Electronics & Information Technology, Government of India. Posted 30th May 2022.
https://pib.gov.in/Pressreleaseshare.aspx?PRID=1829517

REFERENCES

[25] Technology Quarterly Staff, "The cost of training machines is becoming a problem", The Economist. Published June 11th 2020.
https://www.economist.com/technology-quarterly/2020/06/11/the-cost-of-training-machines-is-becoming-a-problem

[26] Rich Miller, "New Generation of AI Hardware Raises the Bar on Cooling", Data Center Frontier. Published September 22nd 2020.
https://datacenterfrontier.com/roundtable-new-generation-of-ai-hardware-raises-the-bar-on-cooling/

[27] "National Strategy for Artificial Intelligence", Niti Aayog Discussion Paper. Published June 2018.
https://indiaai.gov.in/documents/pdf/NationalStrategy-for-AI-Discussion-Paper.pdf

[28] "AIRAWAT: AI Specific Cloud Computing Infrastructure", Niti Aayog Approach Paper. Published January 2020.
https://www.niti.gov.in/sites/default/files/2020-01/AIRAWAT_Approach_Paper.pdf

[29] "India and the Artificial Intelligence Revolution", Carnegie India Brief. Published 11th August 2016.
https://carnegieindia.org/2016/08/11/india-and-artificial-intelligence-revolution-pub-64301

[30] Cem Dilmegani, "AI chips: A guide to cost-efficient AI training & inference in 2022", AI Multiple. Published 19th February 2020.
https://research.aimultiple.com/ai-chip/

[31] "Next-Generation Memory Market size worth $ 25.38 Billion, Globally, by 2030 at 26.19% CAGR: Verified Market Research", Bloomberg. Published 23rd August 2022.
https://www.bloomberg.com/press-releases/2022-08-23/next-generation-memory-market-size-worth-25-38-billion-globally-by-2030-at-26-19-cagr-verified-market-research

[32] Saif M. Khan and Alexander Mann, "AI Chips: What They Are and Why They Matter", Centre for Security and Emerging Technology (CSET). Published April 2020.
https://cset.georgetown.edu/publication/ai-chips-what-they-are-and-why-they-matter/

REFERENCES

[33] Ashraf Eassa, "Pushing Forward the Frontiers of Natural Language Processing", NIVIDA Blogs. Published 16th September 2021.
https://blogs.nvidia.com/blog/2021/09/16/nlp-frontiers-ai-hardware-summit/

[34] Haoting Shen, "Security of AI Hardware Systems." In Emerging Topics in Hardware Security, pp. 95-110. Springer, Cham, 2021.
https://link.springer.com/chapter/10.1007/978-3-030-64448-2_4

[35] Feng, Xin, Youni Jiang, Xuejiao Yang, Ming Du, and Xin Li. "Computer vision algorithms and hardware implementations: A survey." Integration 69 (2019): 309-320.
https://www.sciencedirect.com/science/article/pii/S0167926019301762

[36] "No longer science fiction, AI and robotics are transforming healthcare", Price Waterhouse Coopers (PWC) Blogs. Published April 2019.
https://www.pwc.com/gx/en/industries/healthcare/publications/ai-robotics-new-health/transforming-healthcare.html

[37] Alicia Garcia Herrero, TrinhNguyen and Junyu Tan, "Youthful Asia's Opportunities for Off-Shoring Manufacturing", NATIXIS Corporate and Investment Banking. Published 25th January 2022.
https://www.research.natixis.com/Site/en/publication/Xlz7O9Dgla6RZCtdBlsJy7Y8V2HSBFXUW89jN79FKSI%3D?from=email

[38] Katie Rapp, "Artificial Intelligence in Manufacturing: Real World Success Stories and Lessons Learned", National Institute of Standards and Technology. Published 7th January 2022.
https://www.nist.gov/blogs/manufacturing-innovation-blog/artificial-intelligence-manufacturing-real-world-success-stories

[39] "Agritech - towards transforming Indian agriculture", Ernst and Young (E&Y) Report. Published August 2020.
https://assets.ey.com/content/dam/ey-sites/ey-com/en_in/topics/start-ups/2020/09/ey-agritech-towards-transforming-indian-agriculture.pdf

[40] "Towards Future Farming: How Artificial Intelligence is transforming the Agriculture Industry", WIPRO. Published November 2019.
https://www.wipro.com/holmes/towards-future-farming-how-artificial-intelligence-is-transforming-the-agriculture-industry/

REFERENCES

[41] Press Trust of India (PTI), "Defence Minister to release third positive indigenisation list on Thursday", Business Standard. Published 6th April 2022.
https://www.business-standard.com/article/pti-stories/rajnath-to-release-third-positive-indigenisation-list-on-thursday-122040601115_1.html

[42] Morgan, Forrest E., Benjamin Boudreaux, Andrew J. Lohn, Mark Ashby, Christian Curriden, Kelly Klima, and Derek Grossman, Military Applications of Artificial Intelligence: Ethical Concerns in an Uncertain World. Santa Monica, CA: RAND Corporation, 2020.
https://www.rand.org/pubs/research_reports/RR3139-1.html

[43] Gaurav Batra, Zach Jacobson, Siddarth Madhav, Andrea Queirolo, and Nick Santhanam, "Artificial-intelligence hardware: New opportunities for semiconductor companies, Mckinsey & Company. Published December 2018.
https://www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/Artificial%20intelligence%20hardware%20New%20opportunities%20for%20semiconductor%20companies/Artificial-intelligence-hardware.ashx

[44] "Ethics and Human Rights", IndiaAI, Ministry of Electronics and Information Technology, Government of India.
https://indiaai.gov.in/ai-standards/ethics-and-human-rights

[45] Notification for setting up of Semiconductor Fabs in India, Ministry of Electronics and Information Technology, Government of India. Posted 21st December 2021.
https://www.meity.gov.in/writereaddata/files/Notification%20Scheme%20for%20setting%20up%20Semiconductor%20Fabs%20in%20India.pdf

[46] Express News Service, "IISc develops design framework to build next generation analog chipsets for AI applications", Indian Express. Published 6th July 2022.
https://indianexpress.com/article/cities/bangalore/iisc-develops-design-framework-to-build-next-generation-analog-chipsets-for-ai-applications/

[47] Notification for Design Linked Incentive (DLI) Scheme, Ministry of Electronics and Information Technology, Government of India. Posted 21st December 2021.
hhttps://www.meity.gov.in/writereaddata/files/Notification%20DLI%20Scheme.pdf

[48] Notification for Scheme for setting up of Compound Semiconductors / Silicon Photonics / Sensors Fab and Semiconductor Assembly, Testing, Marking and Packaging (ATMP) / OSAT facilities in India, Ministry of Electronics and Information Technology, Government of India. Posted 21st December 2021.
https://www.meity.gov.in/writereaddata/files/Notifications%20Compound%20Semiconductor%20ATMP%20Scheme.pdf