NATIONAL STRATEGY FOR ADDITIVE MANUFACTURING

Ministry of Electronics and Information Technology (MeitY)
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1. INTRODUCTION

Additive Manufacturing (or 3D Printing)is ushering the world into an Industrial Revolution 4.0, offering immense potential that could revolutionize India's manufacturing and industrial production landscape through digital processes, communication, imaging, architecture and engineering that provide digital flexibility and efficiency. Valued at excess of USD 7 billion[1] in 2017, the industry is growing rapidly, and is expected to be at USD 35.6 billion by 2023[2].

As countries and companies choose to diversify and recalibrate their supply chains, thus restructuring the global manufacturing order, India is faced with a generational opportunity to strengthen its value proposition and realign its global positioning. Therefore, a strategic effort needs to be undertaken to develop indigenous technological capabilities to fully tap and then leverage the potential opportunities of the Fourth Industrial Revolution, and a collective focus on Additive Manufacturing can immensely augment India's efforts to position itself as the Manufacturing Hub of the world.

The Ministry of Electronics and Information Technology (MeitY)is formulating a strategy to promote all sub-sectors within the Additive Manufacturing sector, including machines, materials, software, and design, which will further accelerate the adoption of untapped potential business opportunities in the near future and the execution of recommendations as laid out in the National Electronics Policy, 2019.

Therefore, this strategy document has been initiated to strengthen the action points on Additive Manufacturing in Para 4.4, Para 5.7.1, Para 5.3 respectively, in the National Electronics Policy 2019.

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[1] Robert Bogue, '3D Printing: The Dawn of a New Era in Manufacturing', available at: https://www.researchgate.net/publication/263059946_3D_printing_The_dawn_of_a_new_era_in_manufacturing

[2] TJ McCue, 'Wohler's Report 2018: 3D Printer Industry Tops $7 Billion', available at https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industryrises-21-percent-to-over-7-billion/#2cfa19402d1a

1.1 Genesis of the National Strategy in India

To keep pace with rapid global manufacturing prowess, India needs to adopt an integrated approach to additive manufacturing in all segments including defence and public sectors, especially within the nation's small, medium and large-scale industries. The National Strategy on Additive manufacturing (AM) will aim to create a conducive ecosystem for design, development and deployment, and to overcome technical and economic barriers for Global AM leaders to set up their operations with supporting ancillaries in India, facilitating development of the domestic market and enhancement of global market share.

It will also seek to encourage and promote local manufacturers to seamlessly adopt this emerging technology, creating a support base for foreign companies. Attempts will be made to bring together industry, academia, Government and user organizations on a single platform for information exchange on national priorities, latest innovation and research outcomes, international standards etc., ensuring India optimises the benefits from the commercialization of AM technologies.

Additive manufacturing (AM) is the digital revolution of industrial production that embraces innovation in digital processes, communications, imaging, architecture and engineering to provide digital flexibility and efficiency to manufacturing operations. The computer-aided-design (CAD) software data is used directly to the hardware under this technology to deposit material layer upon layer in precise geometric shapes. Ministry of Electronics and Information Technology (MeitY), being a nodal agency of Digital Technology, is in the process of evolving a strategy to promote all the verticals of the AM sector, including machines, materials, software and designs to leverage the untapped business opportunities in this emerging technology will unfold in the near future.

Vision, Mission and Objectives

Vision

The National Strategy for Additive Manufacturing aspires to postulate the tenets of 'Make in India' and 'AtmaNirbhar Bharat Abhiyan' that advocate self-reliance through technological transformation of the production paradigm.

This discussion paper also aims to inspire an effective strategy on Additive Manufacturing (AM), maximizing economic benefits from future growth opportunities, while minimizing risks and mitigating associated challenges.
The key goals should be to:

- Position India as a global hub for Additive Manufacturing development and deployment

- Create and protect the integrity of India's AM intellectual properties

Mission

- Ensure creation of a sustainable ecosystem for the AM industry to compete globally.

- Encourage AM transformation and driving capabilities in the country for developing core competencies.

- Position India as a global Innovation and Research hub for Additive Manufacturing.

- Ensure AM manufactured end-user functional components for domestic and export markets.

- Promote creation of Indian IPR.

- Ensure adequate measures for the protection of AM technology.

Objective

- Encourage domestic manufacturing across the value-chain to promote Make in India and 'Atmanirbhar Bharat'.

- Increase domestic value addition in core and ancillary components, machines, materials and software.

- Reduce import dependency of domestic market by developing local skill, technology, scale of production etc.

- Encourage global market leaders to establish global bases for manufacturing AM components and sub-assemblies in India, further strengthening India's domestic manufacturing ecosystem.

- Nurture domestic additive manufacturing industries.

- Establish a "National Centre on AM" for harnessing AM transformation and driving capabilities by continuously engaging all key stakeholders.

- Promote Innovation and Research infrastructure for commercialization of end-user application based industrial AM products suited for domestic and global markets.

- Strengthen India's collaborations with global AM organisations and Innovation and Research Centres.

- Create and update innovation roadmap for AM technologies.

- Promote ease of adoption of AM in India by introducing policy interventions that provide graded financial incentives for:

  - enhancing manufacturing capabilities and encouraging manufacturing with foreign technology in India.
  - encouraging and further incentivizing manufactures with indigenous technology that promote a sustainable AM eco-system, both nationally and globally.
  - encouraging export and re-export of machines, materials, AM produced goods and services
  - discouraging import for domestic AM market

1.2 Principles

- Focus on opportunities and corresponding challenges in higher-grade industrial AM technology.

- Long-term economic viability and market dominance of domestic AM companies in strategic sectors and areas of national security.

- Long-term technological leadership through prevention of threats in disruptive AM technologies.

- Gaining user confidence and trust via AM software utility, reliability and ease of access.

1.3 Strategy Targets

The strategy should address key technical challenges faced by AM industries, which include:

(i) Understanding of the properties of the materials

(ii) Limited types of options on AM suitable materials
(iii) Understanding of process technology and performance
(iv) Limited in-process, in-situ monitoring mechanism
(v) Insufficient qualification & certification of AM processes and parts
(vi) Part accuracy
(vii) Surface finish of contoured surfaces
(viii) Fabrication speed
(ix) Build volumes/part size
(x) Data formats
(xi) Lack of AM Standards

2. BACKGROUND

2.1 Technology Overview

Additive Manufacturing (AM) is defined as the technology that constructs a three-dimensional object from a digital 3D model or a CAD model by adding material layer by layer. The addition of material can happen in multiple ways, namely power deposition, resin curing, filament fusing. The deposition and solidification are controlled by computer to create a three-dimensional object.

2.1.1. Global Market Trend

Global spending on AM in 2019 was nearly at $13.8 billion with a growth of 23.5% per annum and expected to reach USD 34.8 billion by 2024, which is growing at CAGR of 23.25%. SmarTech Publishing had estimated the global AM market is 14BnUS$ in 2020 and would reach 41 Bn US$ by 2027, with a year on year growth of 27%. The market share of printers/machines, materials, software and services are 40%, 15%, 15% and 30% respectively. USA's market share on AM is 36%, followed by EU as 26% and China 14% and India holding a meagre 1.4 % of the global market share[3].

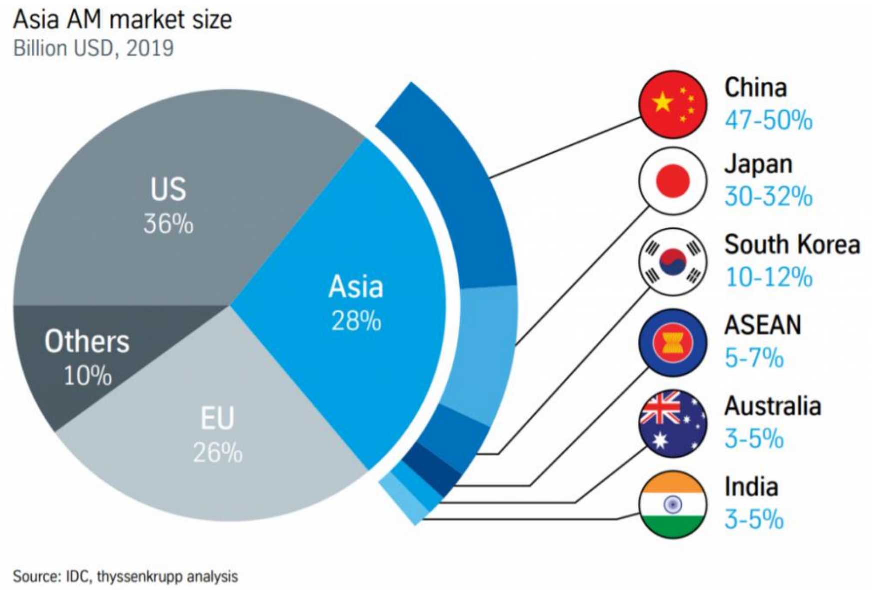

Fig.1 Global Additive Manufacturing Market Distribution[3]

As per International Development Corporation (IDC), Asia's AM spending is estimated at US$ 3.8 billion for 2019, after the United States and Western Europe which account for nearly two-thirds of the overall market (US$ 8.6 billion). Among Asian countries, China holds ~50% of the market, whereas Japan, South Korea and ASEAN hold ~ 30%, 10-12%, and 5-7%, followed by India and Australia at 3-5% each.

Despite this impressive growth, Additive Manufacturing accounts for only around 1% of the global manufacturing revenue[3], and may eventually account for only 5%-10% of total global manufacturing[4]. However, given its revolutionary potential and inherent advantages, a necessary ecosystem must be created and nurtured for maximum adoption and proliferation.

2.1.2 Growth in Market Value

The AM market globally focused on the sectors including automotive, consumer products, medical, business machines, aerospace, government/military, academic and others. Automotive or motor vehicles account for the largest share in this market due to its easy applications in the production of end-products (engines, spare parts, other interior, and exterior parts) as compared to other segments such as consumer products and business machines, which have limited usage in manufacturing of end-products.

The major drivers to propel global AM market are new and improved technologies, financial support from governments, large application area, rapid product development at a low cost, and ease of development of custom products.

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[3]Ibid, pp. 173, 175

[4] Ruth Jiang, Robin Kleer, and Frank T. Piller, "Predicting the Future of Additive Manufacturing: A Delphi Study on Economic and Societal Implications of 3D Printing for 2030," Technological Forecasting and Social Change, vol. 117 (April 2017), pp. 84-97; Terry Wohler's, Ian Campbell, and Olaf Diegel, et al., Wohler's Report 2019 (Fort Collins, CO: Wohler's Associates, Inc., 2019), p. 341; Duncan Stewart, 3D Printing Growth Accelerates Again, Deloitte Insights, at https://www2.deloitte.com/insights/us/en/industry/technology/technology-media-and-telecom-predictions/3d-printingmarket.html.

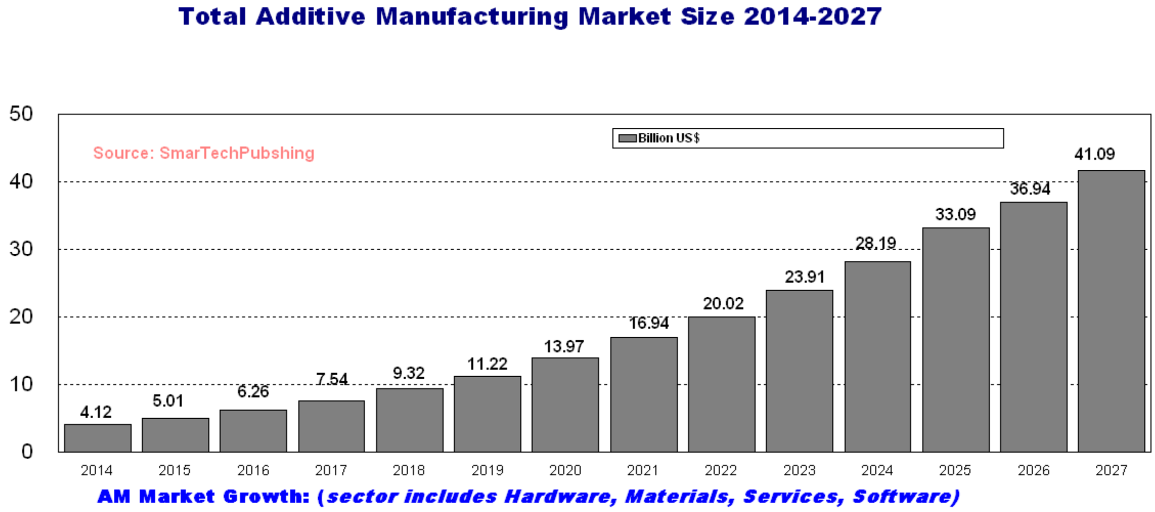

Fig.2 Growth path of Global Additive Manufacturing Market

2.1.3 Geographic Trends

Within the ASEAN region, Singapore, Thailand, and Malaysia account for around 80% of the AM market by value and a similar share of the installed industrial printer base. Vietnam, Indonesia, and the Philippines account for the next 15% of market value, followed by the rest of the ASEAN countries accounting for the remaining 5%. Singapore leads the pack with over a third of the industrial printer installed base and approximately 40% of AM market size, alone, driven by a favourite business environment, and concentrated efforts to grow AM via various R&D centres, universities, polytechnics and research institutions-including the establishment of the national AM Innovation Cluster (NAMIC) in 2015 to translate AM research and development (R&D) into industry.

Table:1: Overview of AM Market in ASEAN (2017)

Countries	Manufacturing Value Addition (Billion USD)	Industrial Printer Installed Base (no.)
Singapore	58.3	100-120
Thailand	117.3	50-60
Malaysia	83.8	30-40
Vietnam	30.4	10-15

Philippines	69.2	10-15
Indonesia	231.3	10-15
Cambodia	3.0	<5
Myanmar	18.8	<5
Brunei	2.2	<5
Laos	1.2	<5

Historical Timeline for Additive Manufacturing Technologies:

1980	Dr. Hideo Kodama filed first patent for RP technology
1984	Stereo lithography apparatus (SLA) was invented by Charles Hull
1986	Carl Deckard invented production of parts by selective sintering
1989	Patent was granted to Carl Deckard for SLA
1990	Fused deposition modelling (FDM)
1992	First SLA machine was produced using 3D system
1996	Clinical application of biomaterials for tissue regeneration
2000	MCP technologies introduced SLM technology
2003	The term ‘Organ Printing’ coined
2004	Dr. Bowyer conceived the RepRap concept of an open-source, self-replicating 3D printer
2005	First colour 3D printer was introduced by Z Corp
2007	Selective layer customization &on-demand manufacturing of industrial parts.
2011	3D printing applied in gold &silver. World’s first 3D printed car, robotic aircraft introduced.
2013	Solid Concepts produced a 3D printed metal gun
2014	Implementation of multi-arm bio printer to integrate tissue fabrication with printed vasculature
2015	First 3D printed pill approved by US FDA. Organovo announced the release of data on the first fully bio printed kidney
2018	MIT developed a novel 3D printing method for transparent glass
2020	3D printers essential in Covid 19 response to build ventilator parts, testing equipment, Personal Protective Equipment and other medical supplies

Source: 3D Printing in Pharmaceutical Sector: An Overview, 2020[5]

[5]https://www.intechopen.com/books/pharmaceutical-formulation-design-recent-practices/3d-printing-in-pharmaceutical-sector-an-overview

2.2 Industrial Applications and Advantages of AM Technologies

A transformational, cross-sectoral and, inter-disciplinary technology, AM is revolutionizing product design and on-location manufacturing globally, enabling radical product design and re-design, which further accelerate development of new material properties, and transformation of business capabilities through production of more sustainable designs realised at lower cost.

Industrial applications and advantages unique to AM include:

Industry	Application	Advantages
Aerospace & Defence	Landing gears, Thrust reverser doors, Small surveillance drones, Gimbal eye, Grenade Launchers, Complex Brackets, and Jet Engine components. Repair of turbine blades and high-value components.	• Low volume production of high value products with complex geometries. • Fuel efficiency through weight reduction of parts. • Improved product utility through on-demand production of replacement parts.
Automotive	Engine bay parts, intake valves, engine components, gear boxes, air inlet, engine control unit, and lower fairing baffle.	• Cost effective solution for Customization of luxury vehicles • Obsolescence Management for defective parts • Testing &Production of lightweight, high strength parts
Electronics	Wearable devices, soft robots, structural monitoring & building elements and RFID (Radio Frequency Identification) devices embedded inside solid substrates.	• High resolution, multi-material, large area fabrication of electronic devices that are free of printed circuit boards (PCBs). • Production of complex, lightweight impact resistant structures with multiple functionality • Designing of complex geometry parts with embedded electronics, sensors and antennas, which cannot be produced by

		conventional manufacturing process. • Internal manufacturing of circuits and circuit boards which reduces procurement time and eliminates intellectual property related issues.
Healthcare	***Surgical Models:*** Organs, Vasculature, Tumor Models, and Disease Models. ***Surgical Instruments:*** Forceps, retractors, medical clamps, and scalpel handles. ***Implants:*** Limbs, Craniofacial implants, Casts, and Stents. ***Dental:*** crown, bridges, and splints.	• Production of customized implants, devices, dental crowns etc. • Reduction in healthcare costs due to minimal re-intervention enabled by accurate diagnosis. • Rapid response time during emergencies through rapid scaling of production. • Staff training in specific applications, leveraging datasets of patients affected by rare pathologies. • Patient centric healthcare through personalisation of drugs for complex patient specific release profiles.
Consumer Goods	Consumer electronics, jewellery, shoes, clothing, cosmetics products, toys, figurines, furniture, office accessories, musical instruments, bicycles, and food products.	• Fabrication of complex internal and external structures compels innovative product design. • Faster time to market and cost-effective customization of customer centric products. • Decentralized manufacturing reducing transferred costs to consumers.

Note: This table is not exhaustive

2.3 Additive Manufacturing Process

Additive Manufacturing technologies are essentially classified into virtual and physical models. The virtual model represents computational models and applications for simulation and optimization. The physical model represents three-dimensional virtual design models that are then speedily fabricated into a physical object. This process is known as rapid prototyping.

The Additive Manufacturing process is detailed below:

Source: Atal Tinkering Lab[6]

Fig.3 Basic Additive Manufacturing process

2.3.1 Design

The Additive Manufacturing process begins with a software programme used to design a digital model for prototyping a physical object, a process referred to as Computer Aided Design. A digital model may also be created through reverse engineering using a 3D scanner. The validation of the technical and commercial feasibility of producing components at pre-production volumes is allowed under AM. Related simulations tools along with production planning are used to capture the shape distortion in the building of a component so geometric adjustments are understood in advance; to find the melt

[6] https://aim.gov.in/pdf/3D_Printing-Guidelines_and_Links.pdf

pool dynamic and residual stress state in the ready component which can be disastrous to its load carrying capacity; to improve the building sequence and/or energy deposition in order to improve the state of the component.

2.3.2 STL conversion and file manipulation

The digital model is then converted to a Stereolithography file (.STL). STL breaks it down into a series of polygons, which represent surfaces of an object, and the model is then fed to a slicer programme/ Computer Aided Manufacturing software (CAM).CAM converts the STL file into a numerical control (NC) programming language - G Code, through which it directly communicates with the machine. This allows customization of design parameters like part orientation, layer height etc.

2.3.3 Printing

ASTM catalogued Additive Manufacturing processes are broadly classified into seven categories, each supported by specific materials and laser-based technologies.

Additive Manufacturing Process

As defined by ASTM F42 the 7 categories of AM process are summarized below:

Process	Technology	Material	Applications
Vat Photopolymerization: a process to selectively cure liquid photopolymer in a vat by light-activated polymerization.	Stereo lithography (SLA), digital light processing (DLP)	Photopoly mers	Prototyping, Consumer Toys, Electronics, Guides and Fixtures.
Binder Jetting: a process to selectively deposit liquid bonding agent to join powder materials	Powder bed and inkjet head (PBIH), plaster-based 3D printing (PP)	Polymers, Waxes	Prototyping and Tooling

Directed Energy Deposition: process in which focused thermal energy ((e.g. laser, electron beam, or plasma arc) is used to fuse materials by melting as they are being deposited	Laser metal deposition (LMD)	Metals	Repairing or building-up of high-volume parts
Material Extrusion: a process to selectively dispense material through a nozzle or orifice	Fused deposition modelling (FDM)	Polymers	Prototyping, Tooling and Office Manufacturing.
Material Jetting: process in which droplets of build material are selectively deposited	Multi-jet modelling (MJM)	Polymers, Waxes	High Resolution Prototypes, Circuit Boards and other electronics, Consumer products and Tooling.
Powder Bed Fusion: process in which thermal energy selectively fuses regions of a powder bed	Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS)	Metals, Polymers	Aerospace, Automotive, Medical products, Tooling and Dental implants
Sheet Lamination: a process to bond sheets of material to form an object	Laminated object manufacturing (LOM), ultrasonic consolidation (UC)	Paper, Metals	Large parts and Tooling

Source: Wohler's Report 2014, https://omnexus.specialchem.com/selection-guide/3d-printing-and-additive-manufacturing-polymers-and-processes

Additive Manufacturing Materials

In myriad applications, the following material categories have been revolutionary in Additive Manufacturing.

(i) Thermoplastics

Thermoplastic polymers are the most popular types of AM materials. Acrylonitrile butadiene styrene (ABS), polycarbonate (PC) and polylactic acid (PLA) each offer distinct advantages in different applications. Water-soluble polyvinyl alcohol (PVA) is typically used to create temporary support structures, which are later dissolved away.

(ii) Metals

Different metals and metal alloys are used in additive manufacturing, which include precious metals like gold and silver to strategic metals like stainless steel and titanium.

(iii) Ceramics

A variety of ceramics including zirconia, alumina and tricalcium phosphate are also used in additive manufacturing. Also, alternate layers of powdered glass and adhesive are baked together to develop entirely new classes of glass products.

(iv) Bio Materials

The biomaterials used in AM applications include the hardened material like silicon, calcium phosphate and zinc to support bone structures as new bone growth occurs. The bio-inks fabricated from stem cells are also being explored by researchers to form blood vessels, bladders and many other human organs. Also 3D Printing of human organs such as liver tissues, kidney, heart etc are being printed using biomaterials and living cells.

2.3.4 Post-Processing

The material needs to be heat treated after AM to get the desired microstructure and mechanical properties. Further reduction of porosity by hot isostatic pressing (HIP) may additionally be required for some applications. The post-process treatments, generally used on conventional produced, are also applicable to AM produced parts. Post processing has the following five major stages like stress relieving, part separation from supports, post heat treatment (to achieve required metallurgical properties), surface roughness improvement, and final machining (to achieve profiles and geometries).

3. INTERNATIONAL SCENARIO

Recent geopolitical and economic instabilities have exposed the jarring fault lines in global supply chains. Governments across the world are leading efforts to identify systemic vulnerabilities, de-risk, and restructure existing value chains. Many countries have taken this opportunity to proactively advocate self-reliance by developing strategies and roadmaps for adopting Advance Manufacturing technologies such as Additive Manufacturing.

Governments of countries such as China, United States of America and Russia have bolstered user-confidence in these technologies through adoption and development of applications for their military forces. For instance, the Additive Manufacturing unit of the US Marine Corps Systems Command has created the world's largest 3D concrete printer capable of printing a 500-square-foot barracks hut in 40 hours[7].

Extensive investments by Governments, Industry, and Academia to advance research and develop intellectual capital assets have further propelled adoption of AM technologies. A recent report by the European Patent Office (EPO)[8]noted patent activity increasing by 239%, from 1,200 applications filed in 2014 to more than 4,000 applications in 2018. Of the patents registered with the office from 2000-18, European countries account for 47% (7,863) of the AM inventions, largely attributable to Germany, which generated 19% (3,155) of all patent applications in AM. The Unites States of America followed with 34.7% of the applications filed, and Japan with 12%.

AM techniques have also witnessed active industry participation, leading to a substantial growth in related research, with the number of publications exponentially rising to more than 4,500 globally, in 2019.

[7]https://www.army-technology.com/comment/3d-printing-and-defence-leading-militaries-named/
[8]European Patent Office, 'Patents and Additive Manufacturing- Trends in 3D Printing', available at http://documents.epo.org/projects/babylon/eponet.nsf/0/C2F0871212671851C125859F0040BCCA/$FILE/additive_manufacturing_study_en.pdf

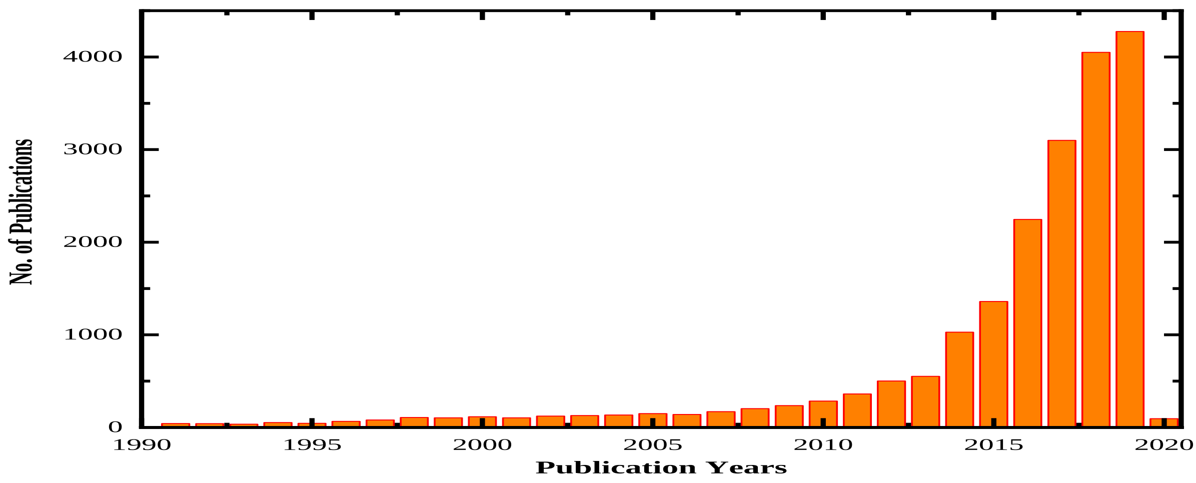

Fig.4 Total number of AM publications globally per year

The collected data on AM publications is based on online research via the search tool 'Web of Science' on 1st January 2020.

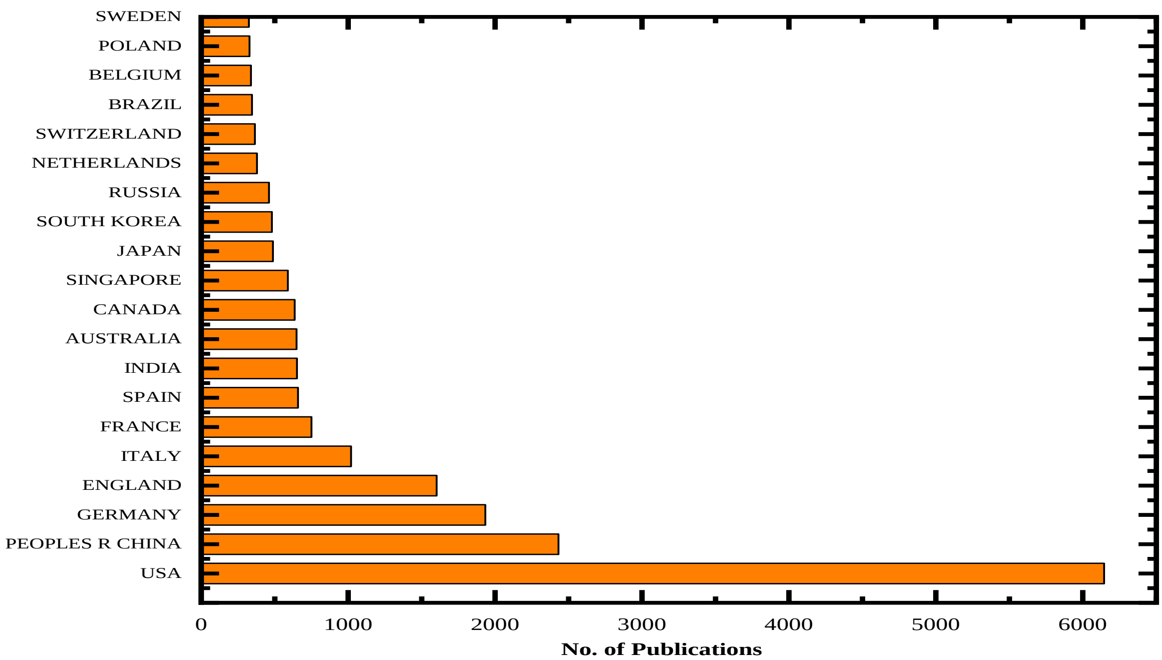

Fig.5 Top 20 countries that work on AM research

The Unites States of America has the highest AM related publications. Government initiatives and programmes have also translated to increased publications for Germany, UK, Italy, and France, while India too has found itself in the top 10 countries for AM related publications.

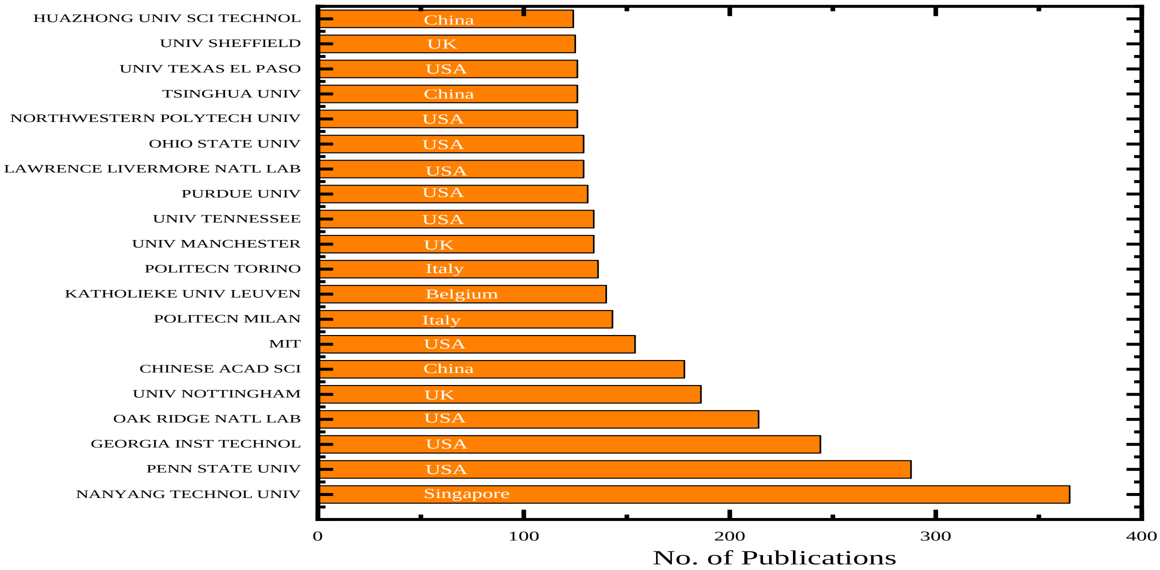

Fig.6 Top 20 organizations that work on AM research internationally

It should be noted that geographical data can skew conclusions, as compared with data from centres of excellence. For example, as a country Singapore is relatively low on the ranking, but from institutional data, we know that Nanyang Technological University is the highest-ranking university in terms of number of publications.

3.1 Key International Developments

Detailed below are some key initiatives undertaken by Governments of countries at the forefront of adopting and advancing AM technologies.

3.1.1 International Strategies & Projects

Country wise initiatives on additive manufacturing:

- ***Canada:*** Multi-Scale Additive Manufacturing Lab
- ***Germany:*** Industrie 4.0
- ***United States:*** Strategy for American Leadership in Advance Manufacturing - 2018, National Network for Manufacturing Innovation- America Makes

- ***Japan:*** Technology Research Association for Future Additive Manufacturing
- ***United Kingdom*:** National Strategy for Additive Manufacturing 2018-2025, National Centre for Additive Manufacturing,
- ***France:*** Industry of the Future
- ***Switzerland/Sweden*:** Swiss-Swedish Innovation initiative
- ***Russia*:** National Technology Initiative
- ***Italy:*** Association of Italian Additive Technologies
- ***South Korea*:** Manufacturing R&D Mid-to Long-term Roadmap
- ***China:*** Made in China 2025 & Additive Manufacturing Industry Development Action Plan 2017-20
- ***Singapore*:** National Additive Manufacturing Cluster (NAMIC)
- ***Australia*:** Advanced Manufacturing Fund
- ***India*:** Make in India
- ***South Africa*:** The Rapid Product Development Association
- ***Morocco*:** The Moroccan Association of Additive Manufacturing and 3D Printing
- ***Egypt:*** Central Metallurgical Research and Development Institute
- ***New Zealand*:** The Titanium Industry Development Association
- ***Taiwan:*** Additive Manufacturing Association of Taiwan

United states of America	***America Makes*:** The flagship institute of AM, National Network for Manufacturing Innovation supports commercialization of AM technologies through ease of access to information resources, IP and research, training of workforce, and development and deployment of AM technologies. ***America Makes and The American National Standards Institute's Additive Manufacturing Standardization Collaborative (AMSC):*** Largely funded by the US Department of Defence, it has published the 'Standardization Roadmap for Additive Manufacturing' and the 'AMSC Standards Landscape' to identify standards, assess gaps and give recommendations. As a result, 'Gaps Portal' was developed to track standardization developments in AM

South Korea	***Roadmap for 3D Printing Strategic Technology, 2014*[9]*:*** The 10-year roadmap identified 15 major strategic technologies in the areas of equipment, material and software for 3D printing in 8 product categories including medicine, defence and electronics. ***The Smart Manufacturing R&D Mid- to Long- term Roadmap, 2015*[10]*:*** Outlined a 5 year plan to invest $376 million in 8 core smart manufacturing technologies, including 3D Printing.
United Kingdom	National Strategy for Additive Manufacturing 2018-2025[11]aims to achieve £3,500M GVA per year by 2025 and 60,000 jobs across sectors The National Centre for Additive Manufacturing aims to commercialize AM adoption in UK.
Japan	The Technology Research Association for Future Additive Manufacturing (TRAFAM) was instituted as a National Project to drive development of Metal Additive Manufacturing systems and technologies for producing high value-added products.
China	***The Additive Manufacturing Industry Development Action Plan 2017-20*[12]*:***It aims to develop a domestic AM industry with an annual average growth rate of 30% or above to exceed $3 Bn by 2020.The plan prioritises a goal to carry out 100 pilot projects across 10 key industries and formalize standardisation of these technologies. 'Made in China 2025'[13]focuses on improving the country's industrial base by integrating technology with industry and fostering Chinese brands in10 key sectors through development of capabilities in Aerospace equipment, high end medical equipment, electrical machines and new materials.

[9] .http://english.motie.go.kr/en/pc/pressreleases
[10] http://english.motie.go.kr/en/pc/pressreleases
[11] Additive Manufacturing UK- National Strategy 2018-2025, http://am-uk.org/wp-content/uploads/2017/11/AM-UK_Strategy_Publication_Amends_Novermber_Digital.pdf
[12] https://3dprintingindustry.com/news/china-action-plan-3d-printing-3-billion-2020-126119/
[13] http://english.www.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm

3.1.2 Talent

Government led initiatives are focusing on upskilling the workforce by developing curriculum specifically for AM in consultation with industry and academia.

China	China founded the world's first 3D printing educational institute, Baiyun-Winbo 3D Printing Technology College in Guangzhou. The Chinese government also installed 3D printers in all of its 400,000 elementary schools[14]between 2015-17 to grow an educated and skilled human resource base for 3D printing. The 'Mass Makerspaces' initiative, 2015[15], extended government support through grants, free office space and subsidised rent to setup Makerspaces for collaborative learning.
South Korea	In 2018, the National Certification test for 3D printing was introduced to provide certifications in 3D printer development and operation[16].
Europe	***Sector Skills Strategy in Additive Manufacturing Project (SAM), 2019[17]:*** This European Commission funded project aims to develop a strategy to anticipate, map and monitor current and future skills in the AM sector to design relevant industry qualifications that address potential skill gaps.

3.1.3 Supply Chain Development

Many countries have made proactive efforts to provide supporting infrastructure and commercial tools to integrate Additive Manufacturing technologies across the value chain.

Germany	The "Platform Industrie 4.0[18]" supports German SMEs with standardization, security, legal frameworks, research, and workforce transformation.

[14]https://3dprint.com/56699/china-3d-printers-schools/
[15]https://www.servicedesignmaster.com/wordpress/wp-content/uploads/2016/10/Made-in-China-Makerspaces-and-the-search-for-mass-innovation.pdf
[16]http://koreabizwire.com/govt-holds-first-certification-test-for-3d-printing/129234
[17]http://www.skills4am.eu/theproject.html
[18]https://www.plattform-i40.de/PI40/Navigation/EN/ThePlatform/Background/background.html

	The State of Bavaria provides incentives such as low-interest loans and non-repayable subsidies and funding to companies for research in emerging technologies such as 3D printing, through the Bavarian Research and Innovation Agency.
United States of America	The National Institute of Standards and Technology's Manufacturing Extension Partnership Centre partnered with 'America Makes' to place trained personnel who link matured technologies developed by the institute with Small and Medium enterprises across the country. America Makes supports a subscription based digital storefront to give member industries access to exclusive information, data and intellectual capital assets.
China	The current patent laws in China recognise most 3D printed designs as IP and extend protection of 15 years from the date of application[19].
South Korea	***Regulatory Approvals***: A fast-track approval procedure for 3D printed medical instruments and devices[20]. ***Tax incentive:*** To promote 3D printing, the South Korean Ministry of Strategy and Finance allowed tax deduction of up to 30% on R&D expenses for small and medium sized companies, and 20% deductions for Large companies and conglomerates[21].

3.1.4 Funding

Countries with leadership in AM have ramped up public funding.

South Korea	In 2014, the South Korean Government invested $2.3 million in 3D printing[22]equipment and facilities for supporting small and medium sized companies. In 2016, the government funded a $20 Mn five-year research project in Ulsan[23]for the development of actual 3D printed ships and offshore equipment. Furthermore, in 2017, the government

[19]https://www.iptechblog.com/2020/08/the-latest-draft-amendments-to-the-chinese-patent-law/
[20]https://www.3ders.org/articles/20160523-south-korea-explores-fast-track-approval-options-for-3d-printed-medical-devices.html
[21]https://www.3ders.org/articles/20160729-south-korean-government-to-offer-significant-tax-exemptions-for-3d-printing-rd.html
[22] https://3dprint.com/169946/south-korea-3d-print-investment/
[23]https://www.3ders.org/articles/20160427-south-korea-to-set-up-five-year-research-project-for-3d-printed-ship-development-in-ulsan.html

	invested $37 million[22]into the development and expansion of 3D printing technology. This was increased to $52.7 million in 2019[24].
Japan	In 2014, $38.6 million[25] in funding was provided by the government largely to support R&D in 3D printers for manufacturing metal end-use products for industrial use. Remaining funds were also directed to the development of super-precision 3D printing technology like Fused Deposition Modelling (FDM), and Selective Laser Sintering (SLS), technology for post-processing and powder recycling, and new 3D measurement devices and image processing software.
United Kingdom	The Government has invested £60 million[26]to establish an 'Aerospace Research Centre' and 'National Centre for Net Shape and Additive Manufacturing' with the emerging 3D printing technology to design and develop products for aircraft landing gear and aero engines.
China	The Additive Manufacturing and Laser Manufacturing Program[27]is a Key Development Programme in the Ministry of Science and Technology's 13th five-year national plan. In 2017, 15 new projects on AM were awarded a total funding of 235 million RMB (~$37.3 million) under the programme.

3.1.5 Research Partnerships

Academia- Industry- Government collaborations and associated consortiums enable innovation by leveraging pooled resources to commercialize academic knowledge that also ensure alignment with national interests.

Germany	Federal Ministry of Education and Research awarded Siemens the opportunity to lead ~ €14 million grant project, entitled "Industrial implementation of digital engineering and additive manufacturing (IDEA)", in partnership with EOS and TRUMPF and institutions including Fraunhofer Institute for Laser Technology (ILT), the Fraunhofer Institute for Production Technology (IPT), and the RWTH Aachen University. The project

[24]https://en.yna.co.kr/view/AEN20190221005000320
[25]https://technology.informa.com/506093/important-regional-developments-for-3d-printing-technology
[26]https://www.spilasers.com/news/uk-government-invests-in-research-centres-in-aerospace-and-3d-printing-technologies/
[27]Wohler's report 2018: 3D printing and Additive Manufacturing state of the industry

	aims to reduce development and production times in powder-based AM by approximately 50%[28].
Singapore	HP partnered with Nanyang Technological University (NTU) and the National Research Foundation (NRF) to establish a $61 million advance manufacturing corporate innovation lab with a focus on additive manufacturing and digital design[29].
United States of America	'America Makes' awarded GE Global $2.6 million to develop an open source, multi laser manufacturing machine, and AM platform to address the challenges faced in Single Laser melting (SLM). This project was planned in partnership with Applied Research Laboratory (ARL) at Penn State and GE Additive[30].

3.2 Global leaders in AM sector

The geographical location of the global leaders in AM under varied verticals including materials, machines, software and services are dominated by USA, Germany and few other European countries. A list of companies with their area of specialization, technology used and geographical presence are provided at **Annexure I**

[28]https://3dprintingindustry.com/news/siemens-to-lead-germanys-industrial-additive-manufacturing-plan-159051/
[29]https://www.3dprintingmedia.network/hp-ntu-singapore-digital-manufacturing-corporate-lab/
[30]https://www.3dprintingmedia.network/ge-global-research-america-makes/

4. NATIONAL SCENARIO

In comparison to some of the leading countries across the globe such as the US, China, Germany and Japan, the adoption of AM hasn't seen as much traction in India. However, it has generated considerable interest in the Indian manufacturing ecosystem, and the platform has been laid to support tremendous growth.

4.1 National Developments

Detailed below are some initiatives undertaken by various stakeholders to develop a domestic AM ecosystem in India.

4.1.1 Government led efforts:

- Establishment of 3D printing Manufacturing Lab at National Institute of Electronics & Information Technology, Aurangabad[31]. The Institute also offers a certificate course in 3D Printing[32].

- ***Atal Innovation Mission:*** Under the aegis of Atal Innovation Mission, Atal Tinkering Labs, 1200-1500 square feet dedicated innovation workspaces have been set up, where do-it-yourself (DIY) kits on latest technologies like 3D Printers, Robotics, Internet of Things (IOT), Miniaturized electronics are installed through government financial support Rs 20 Lakhs so that students from Grade VI to Grade XII can tinker with these technologies and learn to create innovative solutions. As part of the programme, some initiatives such as 3D design challenges were also launched.

- The Gujarat government has signed an MoU with the US Institute of 3D Technology (USI3DT) in California, and OEM 3D systems (a leading global 3D printing companies) for establishing

[31] http://nielit.gov.in/aurangabad/node/15951
[32] http://nielit.gov.in/aurangabad/node/16038/

seven 3D printing Centres of Excellence across seven engineering colleges and technical institutes in the state.

- Andhra Pradesh MedTech Zone collaborated with University of Wollongong to set up a 3D Bioprinting Lab.

4.1.2 Private Sector Initiatives

- INTECH Additive Solutions, Bangalore pioneering in metal 3D Printing in India and the largest commercial set up available. INTECH also developed new software called OPTOMET for development of new parameters and alloys. They have also developed process software called 'AM Builder' for building quality parts at lower cost and user friendly. Also has succeeded in design and development of India's first metal printer under MAKE IN INDIA scheme. INTECH has also started digital academy enabling orientation and training for industry, academia and R&D organisations. Design for Additive Manufacturing (DfAM) is part of the digital academy activities enabling customers to identify design and re-design parts for AM.

- Wipro has launched 'Addwize' - An additive technology Adoption & Acceleration programme with an aim to enable organizations and institutions to systematically adopt and scale the usage of metal Additive Manufacturing (AM) for tangible business benefits.

- Bengaluru based start-up, Accreate Labs & innovation, announced that it will produce user interface panels for ISRO operated GSLV.

4.1.3 Collaborative Efforts

- Department of Heavy Industries' COE at IISc Bengaluru (Additive Manufacturing for High Performance Metallic Alloys) collaborated with Wipro to build India's first industrial grade 3D printer.

- HP Inc has signed an MoU with the Government of AP to build a Centre of Excellence for 3D printing.

- Stratasys has announced a collaboration with NTTF (Nettur Technical Training Foundation) to launch India's first additive manufacturing certification course. The training programme aims to help students learn new technologies in 3D printing, plugging-in skill gaps in the industry.

4.1.4 Academia and Research organisations

AM technology is presently being used in Indian institutions like:

- International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI), Hyderabad (SLM and DED)
- Defence Metallurgical Research Laboratory (DMRL) LENS
- Raja Ramana Centre for Advanced Technology (RRCAT), Indore (LENS)
- Central Mechanical Engineering Research Institute (CMERI), Durgapur
- Central Glass and Ceramic Research Institute (CGCRI), Kolkata (SLM)
- Central Electrochemical Research Centre (CECRI), Karaikudi
- Central Manufacturing Technology Institute (CMTI) Bengaluru (SLM, DED)
- Indian Institute of Technology Mumbai (IITB) (wire-LAM, CMT)
- Indian Institute of Technology Hyderabad (IITH) (Wire ARC)
- IIT Kharagpur (SLM)

- Raja Ramana Centre for Advanced Technology (RRCAT), Indore (*LENS*) and Central Glass and Ceramic Research Institute (CGCRI), Kolkata (*SLM*) have been carrying out AM research on components using Ni and Ti alloys. A research group of DMRL had attempted to build discrete and compositionally graded dual materials based on SS316 and IN625 alloys using LENS™ process. A laser group from RRCAT has developed indigenous laser engineered coaxial powder fed AM system and investigated few alloys at coupon level to study microstructural and mechanical properties.
- International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) and SLM have established a joint demonstration centre at ARCI Hyderabad to develop AM based technologies. Various technologies in aerospace, defence, and automotive sectors are being developed. ARCI also has unique facilities that can cover all the aspects of AM such as software for design for AM, numerical simulation for design optimization, powder development, AM process development using laser powder bed fusion system, HIP and vacuum furnace for post heat treatment and state of the art characterization facilities. It is also actively working on the development of AM technologies for components for various industrial applications and already has obtained expertise in AM of steels, nickel-based superalloys, aluminium, and titanium alloys.

The research being carried out in these institutions is at a nascent stage and has not yet evolved for strategic industrial integration in sectors like aerospace. Private industries too are exploring plastic and metal AM technologies such as laser wire deposition, TIG, LENS and direct metal deposition, along with laser powder bed methods such as laser sintering, laser melting and electron beam melting. The production of components through AM by these companies is based on technical parameters given by the suppliers.

4.2 Potential Impact of Additive Manufacturing:

Evidently, Additive Manufacturing is expected to impact the manufacturing ecosystem significantly. The technology is likely to have a relatively different impact across different sectors.

4.2.1 Economic Competitiveness

Supply Chains

- Upstream Supply Chains will be flattened and simplified as semi-fabricated products replace raw materials. AM will enable supplier consolidation as a single source may suffice for a variety of parts, increasing production agility. Consequently, procurement costs will decrease due to lower labour costs associated with fewer manufacturing touch points.

- Production AM technologies will enable fast and cost-effective manufacturing of smaller batches, and greater product customisation thereby eliminating the need for tooling and moulds. Traditional manufacturing processes may be reduced to a single step process.

- Downstream Supply Chains will also consolidate as warehousing and distribution channels rationalize due to on-demand manufacturing of multifunctional products and spare parts, thus reducing physical inventory and associated costs. Direct customer delivery will also become feasible for manufacturers.

Increase in Gross Value Addition (GVA)

AM will ensure democratization of innovation by empowering individuals to create and actively participate in the global value chain thereby developing new technology-driven industries and jobs. This will also accelerate the growth of new support industries. The growth and assimilation of AM technology in the Indian manufacturing sector will have important effects on Indian macroeconomic statistics and enhance India's economic power.

Workforce

The productivity is a contributor to the reduction of employment in manufacturing. Even if, AM results in a significant increase in productivity that attracts other jobs, it may fail to net increase employment in manufacturing. AM may, however, facilitate a net increase in employment through new products and other means. Effective measures must be adopted to proactively provide skilling and upskilling programmes on AM to ensure a technically competent, readily available workforce.

4.2.2 Social Implications

AM has significant potential to contribute to sustainable development. It results in a considerable reduction in use of raw materials due to material efficient designs and obviating (or significantly reducing) the need for manufacturing tools, dies and moulds. Indirectly, AM also facilitates development of new materials and technologies which are more energy and resource efficient. These advantages would enable India to alleviate its carbon footprint and increases its energy security by minimizing its dependence on fossil fuel imports.

4.2.3 Innovation Diffusion

AM enables greater design flexibility through modification of virtual designs models and new material properties. It allows for limited design constraints without the risk of high expenditure thereby boosting innovation in the product development process. Enhanced product differentiation and flexibility in design innovation through AM enables ease of access for smaller businesses to new and high value markets.

4.2.4 Healthcare

Additive manufacturing has the potential to fabricate biomedical implants, prosthetics, skin and tissues and intricate organs. Specialised surgical instruments and medicals devices can be manufactured quickly and cost effectively. In this way AM technology is going to create the patient specific medical care in the future.

4.2.5 Military Superiority

Technological advancements in AM has the potential to fortify India against military and cyber warfare.AM technology also promises to transform the Indian military supply chain system. In place of storing important stocks, our military entities will only require adequate AM facility and important raw materials to help the manufacturing process even in the severe places. Transformation of physical inventory into a digital one will help in reduction of supply chain overhead, conveyance costs and additional logistical challenges faced by military forces in the battleground.

4.3 Focus Sectors

The potential of AM is growing very rapidly, and the global value of the industry has increased from US$1.71 Bn in 2011 to US$ 13.8 Bn in 2019, a rate of more than 25% per year since 1989. The 5-year growth outlook for these technologies averages to 23.5% per annum, almost doubling every three years. This is the next wave of technology driven industrial growth and to achieve self-reliance in its manufacturing ecosystem, India must focus on accelerating this adoption.

Detailed below are sectors where potential application of AM technologies may reap digital dividends that will further strengthen and de risk India's supply chains.

4.3.1 Electronics

Electronics sector suffers a disability ranging between 8.5-11%[33] on account of inadequate infrastructure, high cost of finance; domestic supply chain and logistics; unavailability of quality power; limited design capabilities and focus on R&D by the industry; and inadequacies in skill development. The import dependency on electronic components has a significant impact on cost of production of allied industries like Automotive, Defence and Aerospace, Medical Devices etc., thereby hindering India's capabilities to develop a self-reliant manufacturing ecosystem.

Electronics is a high-volume manufacturing sector. As AM manufactured electronics is only suitable for low volume prototyping, its proliferation in electronics has been relatively slow. The demand for 3D printed electronics is coming from many applications areas such as regular and special circuit boards, high frequency antenna for satcoms, anechoic chambers and mobile handset. Other key application areas are smart glass, power electronics, sensors and non-electronic components in electronics such as mobile accessories, computer motherboard backplane, decorative lamps etc. Normally, AM for electronics involves jetting of material, in which conductive and insulating inks are jetted on to a platform in microns and ultraviolet light solidifies the inks. The significant feature of this jetting process is that it helps in multi material jetting. This helps the electronics industry in fabrication of functional circuits and enclosures at once, thereby simplifying and shortening the process of assembly.

The recent development of low viscosity techniques such as aerosol printing has been able to demonstrate a faster process and could be suitable for commercial products such as mobile antenna. Since most of the electronic components are nanometre-sized, there is a need to develop nanoscale materials for additive manufacturing.

[33] https://www.meity.gov.in/esdm/pli

Additive Manufacturing is generally used for prototyping applications in the electronic industry. However, the layer-based process provides potential applications in real-time health care and automotive industry too, as it provides access to individual layers during fabrication, also supports a unique architecture for a single object with multiple materials and embedded components.

Apart from applications, advancements in design software is imperative as it describes the arrangement of electronic components that can be printed inside the component itself. Although it is ata nascent stage of development, it shows potential for industrial use cases.

Electronics for AM Machines

With advancement in industrial application of AM in various sectors including aerospace, building construction, military, defence, and healthcare, supporting industries such as electronic components and photonics used for developing these AM machines will also see a commensurate growth. Electronics materials such as metals, ceramics, polymers, glass and semiconductors have been printed with minimum dimension of few microns and all basic components of electronics such as resistor, capacitor, inductor, filters, PCB substrates, waveguides, transformers, ferrite core, motor, electromagnet and so on had been successfully demonstrated. The fundamental electronics required in AM machines include modules (including special types of printed circuits boards), passive and active components, SMD components and so on.

The Ministry of Electronics and Information Technology has reinforced its commitment to develop the domestic electronics ecosystem by introducing schemes such as the Production Linked Incentive (PLI) for mobile handset manufacturers, Scheme for Promotion of Manufacturing of Electronic Components (SPECS) and Semiconductors (SPECS), and Electronic Manufacturing Clusters

(2.0).These schemes aim to anchor part of the production base of global electronics manufacturers and their downstream suppliers to India and help India integrate into global supply chains. This provides an opportunity for Indian electronics component manufactures to adopt advanced technology from foreign OEMs, actively adapt to market demands and strengthen the national manufacturing base of electronic circuits, antennas, sensors, moulded interconnected devices, resistors, conductors and semiconductors for product development and advancement of functional applications of AM machines.

4.3.2 Aerospace

Currently, presence of Indian private players in the Aerospace Industry is limited to Tier 2 (Avionic and flight systems), Tier 3 component manufacturing (castings, forgings, Power electronics components, cables, wiring etc)and design Engineering and IT solutions. To support the upward mobility of domestic manufacturers in the value chain, government and private sector partnerships are recommended through strategic investments in advanced technologies like AM.

The aerospace sector is dependent on materials such as special alloys of steel, aluminum, titanium etc and composites for production. Currently, about 70% of these raw materials[34] required are imported, largely due to lack of in-house R&D and a strong vendor base. Import dependency of electronics components also is an impediment to scale domestic production of products like satellites. In fact, over 50% of the electronic components used in a large satellite, and 10% used in a rocket are imported[35].

The airline industry was one of the earliest advocates of AM and is also responsible for its advancement in both end-use parts manufacturing and prototyping. The evolution of material engineering

[34] CII, India as an Aerospace Hub – Opportunities, Challenges and the Way Forward, Available at: http://cdtioficial.es/recursos/doc/Programas/Cooperacion_internacional/Bilateral_India/Documentacion_relacionada/37977_1561562017115450.pdf
[35] t.ly/fMXu

capabilities of these technologies provides a promising opportunity for domestic manufacturers to adopt AM methods, using custom alloys and high-end thermoplastics to develop lightweight vital components for aircrafts and spaceships thereby reducing import dependency on raw materials. Rapid on-demand production of aircraft parts further saves space, time, and money, supporting domestic manufacturers to capture a larger share of the value chain.

India is expected to purchase approximately 750[36] aircraft and helicopters in the Defence sector. Moreover, the total defence MRO market segment in India is projected to reach approximately $2.5 billion by 2025[36]. Reverse engineering capabilities of AM technologies are well suited to help capitalize on this opportunity by aiding repair and obsolesce management of aircraft components.

4.3.3 Defence

India is currently the second largest importer of defence equipment. Imports by Ordnance Factory Boards and Defence Public Sector Undertakings are estimated to be INR 20,000 crore annually[37].Digitization of defence forces is imperative to build required infrastructure to protect the sovereignty of India against cyber warfare, biowarfare and strategic warfare.

India gives orders worth $100 billion[38] a year for defence procurement, making it one of the world's most attractive markets for defence companies. Revised FDI norms have now allowed 74% foreign investment in the defence sector under automatic route and 100% though Government approval route. This will provide incredible impetus to private companies to acquire advanced 3-D technology from foreign OEMs. The new offset guidelines also extend higher multipliers for Transfer of Technology to private companies/DPSUs/ DRDO and OFB to further enable acquisition of niche AM technologies

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[36] t.ly/0fSP
[37] https://www.thehindubusinessline.com/economy/need-to-upgrade-ordnance-factories-to-lower-import-dependence-say-defence-experts/article32345265.ece
[38] t.ly/O03L

to strengthen Indian defence forces. Moreover, the Defence Procurement Policy 2020 promotes indigenous design capabilities and higher localisation to increase participation of the domestic industry.

4.3.4 Automotive

India imported auto components worth USD 17.6 billion, of which 27% (USD 4.75 billion[39]) was from China during 2018-19. Imports of drive transmission and steering parts, electronic and electrical items, cooling systems, suspension, and braking parts are dominating from China. Apart from the cost differential, lack of competence on technologies in segments including BS-VI components and electronics has further worsened the disability in domestic production.

The Indian Auto sector constituted 7.5%[40]of the GDP in FY19, and has been at the forefront of adoption of AM. AM technologies can be utilised to reduce import dependency by improving the cost advantage of manufacturing in India. On-demand production of tooling and spare parts drastically lowers the cost of inventory. Rapid tooling also helps reduce redundancy of the traditional production process, saving on time and costs. Ashok Leyland, the Indian manufacture, has been able to save Rs 74 lakh of manufacturing cost and 14,138 days of hour-utilization through Stratasys' additive manufacturing technology.[41]

Automakers rely on production processes that achieve better fuel efficiency and economy to grow revenue and deliver greater value to customers. This may be enabled through AM that allows more complex designs that overcome the need for multiple parts and permit weight reduction by making alterations at a structural level. Adoption of such technologies becomes instrumental as vehicle Fuel efficiency norms get stricter in India.

[39] https://economictimes.indiatimes.com/industry/auto/auto-news/indian-auto-component-industry-aims-to-cut-dependence-on-chinese-imports-acma/articleshow/76546035.cms?from=mdr
[40] t.ly/kw5q
[41]https://auto.economictimes.indiatimes.com/news/auto-technology/additive-manufacturing-tech-to-revolutionize-product-designing-in-auto-sector/72106045

As automakers migrate to BS-VI norms, AM offers the benefit to test these solutions as functional prototypes in smaller batches with shorter production cycles. It also enables flexibility in customization of pre-production 3D design files to meet structural requirements.

AM technologies also present opportunities in the Advanced Mobility segment due to their material engineering offerings and capabilities.

4.3.5 Medical Devices

The domestic medical devices ecosystem faces a significant produ70-90% of domestic demand for medical devices are met through imports, of which the US, largest exporter to India, contributes 25-30%[42]. Diagnostic equipment is the most imported, while other imports include imaging devices such as scanning apparatus, X-Ray machines, and Computer Tomography Apparatus. Currently, manufacturing within India is largely limited to disposables and consumables.

The Medical Devices segment is expected to grow at a CAGR of 16%, and will become a $25-30 billion industry by 2025[43], significantly higher than the global industry growth in terms of cost. It is estimated that the share of medical devices, along with diagnostic services, constitutes 20- 25% of all healthcare costs[43]. It also contributes to about 30-40%[43] to costs of establishing a tertiary care hospital. This sector can gain from lower production costs through adoption of AM, as it enables shorter supply chains due to lack of tooling, reduced inventory, supplier consolidation and lesser wastage. This in turn may translate to lower healthcare costs, making such services cheaper and more accessible.

[42]https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/india-must-aim-at-medical-devices-import-substitution-eepc-india-deloitte-report/articleshow/75421694.cms?from=mdr
[43]Deloitte, Medical Devices Making in India - A Leap for Indian Healthcare, 2016, available at: https://www2.deloitte.com/content/dam/Deloitte/in/Documents/life-sciences-health-care/in-lshc-medical-devices-making-in-india-noexp.pdf

As per NSO[44], the percentage of people in India with disability was 2.2% -2.3% in rural and 2.0% in urban areas. Moreover, India is witnessing a rise in road accidents with 4,67,044[45] road accidents reported in 2018. However, currently, a prosthetic leg from a private centre in India costs between INR 8 lakh to over INR10 lakh[46].

AM provides customization flexibility using cross sectional imaging from datasets obtained from CT/MRI scans to build a 3D anatomical model with geometric complexities specific to the patient. Customized, high-tech and multi-functional3D printed prosthetic limbs in India are less than half the cost of the ones imported, which are upwards of INR1.5 lakh[47], with some starting as low as INR 40,000[48]. Government Centres providing artificial limbs require upgraded technology to be able to provide more sophisticated products, and effectively utilise the material engineering benefits of AM to provide subsidised prosthetics.

4.3.6 Capital Goods

Some of the products are manufactured in India by the Capital Goods sector such as earthmoving and mining machinery, textile machinery, heavy electrical equipment, machine tools, printing machinery, food processing machinery etc. India imported $12.78 billion[49] of capital goods during March 2019 to February 2020 from China, making it the second largest category of imports after electronics, televisions and electrical appliances ($18.12 billion[49]). India's total commodity import bill from China for this period was $49 billion[49]. The low technological competitiveness of the Indian Capital Goods sector has proven to be a major impediment to the growth of this sector.

The Capital Goods sector is instrumental to the industrial growth of India as it is the backbone for the manufacturing base of allied

[44] https://pib.gov.in/PressReleasePage.aspx?PRID=1593253
[45] https://pib.gov.in/PressReleasePage.aspx?PRID=1592206
[46] t.ly/pktz
[47] https://www.hindustantimes.com/delhi-news/customised-high-end-prosthetics-that-don-t-burn-a-hole-in-your-pocket/story-a6p6VtyVzuXjwPriSrOhNO.html
[48] https://timesofindia.indiatimes.com/india/3d-printed-limbs-give-disabled-a-helping-hand-and-leg/articleshow/66857981.cms
49 https://www.thehindu.com/business/Economy/indias-imports-from-china-rise-in-june-and-july/article32320584.ece

industries. Sustainable and innovative mechanization is needed to address issues of crop burning and capitalize on India's farm equipment market which is likely to grow to USD 18 billion by 2025[50]. Additive Manufacturing supports tooling by enabling low cost- on demand production of replacement parts in sub sectors with immense investment potential such as agricultural machinery.

Additive Manufacturing machines are also equipped to manufacture using a variety of metals through the appropriate print head. Technologies such as Selective Laser Melting (SLM) and Selective Electron Beam Melting (SEBM)-based powder bed processes may be utilised for making complex metallic objects. Advanced AM machines can provide high speed and drive down costs low enough to cater to mass production. There would be cost savings arising out of weight and energy saving over the product life cycle as well as in post processing.

4.3.7 Consumer Goods

The consumer goods sector is extremely price sensitive and is highly dependent on imports to meet the growing domestic demand. Products in this sector include furniture, office accessories, toys, figurines, art, jewellery, museum displays, musical instruments, and fashion products among other items.

Jewellery manufacturing in India is one such sub sector with the potential to become self-reliant. However currently, China constitutes 35-40% market share of India’s Rs 35,000-crore fashion jewellery business[51]. India is also the largest importer of gold, importing around 800-900 tonnes annually, largely to cater to the demand of the domestic jewellery industry[52].

50https://www.business-standard.com/article/news-cm/india-s-farm-equipment-market-likely-to-grow-to-18-billion-by-2025-from-13-billion-119120600498_1.html

[51] https://economictimes.indiatimes.com/industry/cons-products/fashion-/-cosmetics-/-jewellery/imports-of-cheap-imitation-jewellery-from-china-may-come-down/articleshow/76372606.cms?from=mdr

[52] t.ly/QD3a

The consumer goods segment is characterized by rapidly changing consumer needs and demand for customer centric products and personalization. The Gems and Jewellery (G&J) sector itself contributes to 7% of the country's GDP and constitutes 12% of its exports[53].AM is well suited to enable reduction in cost of raw materials for this sector through its layer-based production process which may reduce the requirement and wastage of high value materials. Further, AM's compatibility with advanced materials provides alternatives for fabrication of cheaper, lightweight more resistant products. The design freedom promised by AM allows intricate customizations to develop bespoke products with complex geometries through on demand production thereby satiating the fast-evolving demands of this sector.

4.3.8 Construction and Architecture

In India as of March 2020, as many as 403 [54]infrastructure projects, each worth Rs 150 crore[54] or more, have witnessed cost overruns of over Rs 4.05 lakh crore[54]. Historically reasons for such delays include changes in design and specifications, design errors, incomplete design, changes in scope, additional works, delay in design delivery, which translates to delayed construction, excess contractual claims, disputes at site and poor project management.[55] Moreover, the majority of the materials used in construction sector, especially, those in high-end category falls in the 28% GST slab and has been a great impediment for all stakeholders.

Additive Manufacturing technologies have been primarily used in developing housing fabrication, construction components (cladding and structural panels and columns), bridges and civil infrastructure, artificial reefs, follies, and sculptures. AM technologies have given a new dimension to construction and architecture by meeting complex designs of modern architecture through compatibility with a variety of

[53] http://timesofindia.indiatimes.com/articleshow/77278376.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
[54] t.ly/ICyE
[55] Factors influencing cost over-run in Indian construction projects,2017,A.Cindrela Devi and K.Ananthanarayanan, accessed at https://www.matec-conferences.org/articles/matecconf/pdf/2017/34/matecconf_ascm2017_02023.pdf

materials. AM also offers design flexibilities which can be used for building complicated geometries and to optimize large scale model making or shadow studies to reduce material wastage. Geographic Information Systems AM data can also be printed to show actual city landscapes. Innovative technology developed by IIT Madras and an Indian startup allows for concrete to set in 3-5 hours as opposed to the traditional timeline of 28-30 days taken for curing. Therefore, AM is a promising technology for reducing time and costs of construction.

4.4 Challenges to Adoption

4.4.1 Cost of Equipment & Material

Since AM technology in India is still evolving, the equipment and material costs are high. Most of the industrial grade AM machines and raw materials need to be imported. Therefore, the higher pricing structures for AM machines and materials in India make entry more expensive when compared to other manufacturing techniques such as CNC machining and injection moulding.

4.4.2 Lack of formal AM Standards

As industrial AM is still in the early stages of development, there is a lack of formal AM industry standards. ASTM international (American Society for Testing and Materials) has made an ASTM F42 standard for metal powder bed processes to standardize the quality for critical aerospace, automotive and medical industry. However, the scope of the standards is limited and a lot more work is needed. Standardization of materials, machines and processes will ensure the quality and functionality of AM manufactured components, which will further build confidence and encourage the adoption of AM technology.

4.4.3 Lack of AM Ecosystem

Service providers in India are limited and most are not equipped with competitive AM technologies compatible with materials such as plastic, metal, ceramic. The AM ecosystem needs to develop by aggregating all service providers under a single platform to provide comprehensive AM solutions.

4.4.4 Monopoly of AM market by foreign OEM's

Most of the AM Original Equipment Manufacturers (OEM) are foreign companies. This has created a monopolistic approach towards consumables, which are therefore very expensive and thus hamper the adoption of AM technology.

4.4.5 Lack of skilled manpower

The paradigm shift in design and production processes through AM requires a workforce with a technical know-how of the technologies. Lack of trained and experienced engineers and designers is a major impediment to the adoption and advancement of AM.

4.4.6 Domestic Market Transition

The reduction in physical production footprints with AM adoption may vacate large factory space and creating obsolete traditional manufacturing equipment may raise questions on how to repurpose, recycle or dispose of this infrastructure. Moreover, fall in demand of the manpower with traditional manufacturing skills would lead to significant unemployment and subsequent large-scale retraining programmes for them, especially for the blue collar workers with low to medium salaried class. The supply of AM skilled manpower may also be a challenge for keeping up with the demand, and would create hurdles for the growth of the AM industry. The AM adoption will allow manufacturers to eliminate intermediate steps in prototyping, product design, and supply chains, which further result those service companies out of business. These transition issues discourage manufacturers from embracing AM on a larger scale though potential benefits in terms of cost, time and energy savings are known.

4.4.6 Lack of clarity around the issue of liability

Additive Manufacturing has the potential to conflate several different classifications on which current laws and standards are built. For example, Additive Manufacturing could blur the lines between manufacturers and consumers as consumers themselves can manufacture goods for consumption. Raw materials used by the consumer in such cases are merely a CAD file and ink while the printer acts as a device. Laws and regulations, as they stand today, do not account for such a scenario and hence it may be difficult to fix liabilities in case of an error. Such lack of clarity also has practical implications. For instance, automotive manufacturers may be reluctant to include 3D printed components in their cars as they would not be able to hold the supplier liable in case of any faults. This could lead to lower adoption due to low demand. Several laws will have to be tweaked to account for this new technological development. From consumer protection Act to criminal laws, everything will have to be revisited to establish a comprehensive legal regime for affixing liability.

4.4.7 Legal & Ethical Issues

As a new technology, the first challenge may focus on laws related to intellectual property, and possible concerns around trademark and design violations as manufacturing gets democratized significantly. Additionally, several sector specific laws may also have to be tweaked to adequately address the challenges. For example, in the Pharma and Medical devices sector, questions such as, whether downloading a CAD file for the purpose of producing a drug through AM technologies amounts to import under the relevant laws or whether a CAD file is in itself a drug or a medical device, are some of the very critical questions which will have to be addressed if Additive Manufacturing has to realize its true potential. Similarly, AM can provide a less traceable and more cost-efficient means of acquisition and production for complex parts like nuclear centrifuge or missile components.

In addition to these legal issues, Additive Manufacturing raises some critical ethical concerns, especially around bio printing. Even with the current level of maturity in the technology, it is possible to print organs which are more advanced than regular human organs. This in many ways is akin to issues raised against gene-editing and presents its own challenges. Updating our regulatory architecture to address these emergent (legal & ethical) issues can engender a conducive framework for increased AM adoption.

5. ACTIONABLE RECOMMENDATIONS

To position itself as a pioneer in restructuring its supply chain, India must adopt Additive Manufacturing technologies in all manufacturing segments including defence and public sectors. The National Strategy on AM should aspire to create a conducive ecosystem for design, development, and deployment of these technologies.
Detailed below are certain measures that could be undertaken to promote adoption of Additive Manufacturing technologies in India to achieve these aspirations.

5.1 National Additive Manufacturing Centre

A dedicated agency may be constituted to spearhead the National Initiative for positioning India at the forefront of development and adoption of Additive Manufacturing Technologies. The Centre could be mandated to act as an aggregator of knowledge and resources, and an accelerator for technology adoption and advancement.

- An Apex Body should be established with subject matter experts from Industry, Academia, Research Institutions and Government Ministries and Departments. The initiatives detailed below could be undertaken in consultation with all members.

- A detailed study be commissioned to analyse:

  - The current ecosystem for manufacturing of AM machines in India, the existing disabilities and import dependency across the supply chain be identified to develop a strategy to indigenize manufacturing. Accordingly, development of a Phased Manufacturing Programme for AM machines may be recommended.

  - Analyse sectoral potential for integrating AM technologies (advantages, opportunities, and limitations) and align them with

National priorities to identify critical sectors for channelizing public and private sector investment.

- Through consultations with State governments and Industry, regional sector specific industrial clusters with potential to integrate AM technologies and localize supply chains be identified. A long-term strategy could be developed for building on supply chain strengths and for addressing deficiencies.

- A skill gap study be undertaken to track the demand and supply parity in the workforce requirement for adoption of AM technologies. New job roles be identified and mapped to the National Skills Quality Framework. Recommendations could be given on skills and competencies required for existing and new job roles created.

- The centre could be mandated for the development, deployment and transfer of AM technologies by undertaking the following measures to address the key technical challenges corresponding to the adoption of AM:

  - ***Process***: In order create a niche market space in AM sector technological advancement in faster, accurate, high resolution, large format-built capacity AM machines would be needed. Wider adoption of AM could be supported through the development of process control, machine robustness, open platform equipment, and new AM process capabilities to enhance applications of AM for various sectors.

  - ***Standard***: Development of robust qualification and non-destructive testing (NDT) would be important to address standardization issues and ensure quality assurance through in-situ monitoring and control methods. It would also help to achieve AM process stability, repeatability and reproducibility and non-destructive post-AM detection and control of defects.

The parts produce through AM process are naturally anisotropic. Though, numerous studies are carried out to examine the porosity as a function of process parameters, however, very few could linked the results to mechanical properties. It will be important to map the porosity to thermo-mechanical properties (static, and cyclic) and also using the data to identify the right NDT methods as well as to determine the probability of detection a critical defect size. The standardized protocols for post processes such as hot isostatic pressing, heat treatment and shot peening will be required. The Non-Destructive Evaluation (NDE) methods are required to be ensured for both in-process and post-process applications using various in-situ sensors for monitoring. National laboratories on Standards should be engaged to address these issues to ensure global acceptability of these standards.

- ***Certification***: Development of requisite AM standards and protocols for India through active participation in relevant global forums and extensive public-private consultations with academia, R&D institutions, and industry experts.

  AM is greener approach to manufacturing, however, presence of metal powders, laser radiation and toxicity risks from chemicals in AM are akin to other technologies. To address these issues, the global standard bodies are bringing AM specific safety standards such as UL 3400 and are also working on developing standards through the ASTM F42 committee. India could also adopt these standards through its existing standard eco-system to nurture a globally competitive domestic AM ecosystem

- ***Materials:*** Focus on development of advanced materials for industrial application in defence, aerospace, automotive, biomedical, industrial applications, electronics etc is needed. Defining standards for material requirements and establishing materials qualification and certification, to be prioritized.

Strategic focus needed to ensure development of - AM material to improve component performance, single source of material, process and functionality documents, and for advancement in material research.

- ***Software & Design***: Development of design tools and Design for Additive Manufacturing (DfAM).The streaming of machine instruction for fabrication through a reduced cycle time and development of higher functionality products needs to be ensured.

- ***Legal Framework***: Strengthening existing cyber laws is required to effectively ensure risk mitigation and safety of AM CAD files, software, and hardware, along with the security of AM database structures, and timely detection and incidence response for cyber attacks on AM systems. It is imperative to build capabilities in the private sector to mitigate the risks of IP infringement in AM technology. India should prioritize the development of cyber security tools for prevention and timely detection and mitigation of compromised data. A proactive approach towards addressing Liability and Intellectual Property concerns may also be adopted to prevent the emergence of risks rather than regulating them once they present themselves.

- Development of a strategic AM Technology Advancement Plan to chart out R&D and IP creation priorities may be undertaken. Existing Government programmes and public funded research should be analysed to ensure alignment to this plan, to avoid duplication of efforts, and to ensure that investments meet mission needs. A broad framework of the priority areas has been detailed in **Annexure II**

5.2 Strengthening Technology Leadership

5.2.1 Talent

The National Strategy should address the need for skilled manpower in various job profiles including operators, engineers, R&D personnel, technology broking and management.

The following policies will be important for AM related manpower development:

Academic Institutions	• Engineering curriculum suitable for bachelor and master's degrees may be developed through the University Grants Commission (UGC) and All India Council for Technical Education (AICTE) in consultation with Industry and be introduced in ITI's/NIT's/IITs. The curriculum should focus on the fundamentals, applications and implications of AM for design and manufacturing, product design and development, machine design and development, material development characteristics and applications, production process optimization, applications of AM technology in space, aerospace, defence, automotive, navy, biomedical and engineering. • NSQF standardized and certified Open Access/Free Online Resources, diploma, and certification courses could be provided with customizable and self-paced training modules to all educational levels. A special curriculum for training of teachers could also be developed to acclimatise them with the technology. • Inclusion of STEM in school curriculum as it prioritizes inquiry-based learning and critical thinking skills to solve application based problems by using an engineering design approach. • Lab based training initiatives like Atal Tinkering Lab to be undertaken to inculcate skills like computational thinking, design mindset, adaptive learning, physical computing etc

	• Industry should also be encouraged to open AM centres at academic institutes for proliferation of different AM technologies and development of skilled manpower. Financial support could also be extended through Government and industrial funding via academic institutions.
Workforce	**MakerSpaces and FabLabs** • National network of Industrial MakerSpaces and FabLabs may be developed through a Public Private Partnership (PPP) framework for encouraging community participation to promote the horizontal exchange of knowledge. • This initiative could be modelled around 'Maker Village', a Government- Academia collaboration between MeitY, IIITM-K, Government of Kerala and Kerala Start-up Mission. The institute provides facilities for ideation of product development including co-working spaces, conference rooms, electronics and Instrumentation labs, Metal Machining area, Industrial 3d Printing and Plastics facility, and an Industrial SMT Line. It also provides financial assistance and co investment opportunities.
	Skilling &Upskilling • Industry driven apprenticeship programmes should aim to inculcate the knowledge, skills and behaviour required for specific job roles, to operate in an end to end additive manufacturing production environment. • To incentivize organizations to invest in re skilling their workforce, a certain percentage of CSR fund may be permitted to be utilized for this purpose.
	Technology Centres • At present, 76 courses offered by MSME TCs are National Skill Qualification Framework (NSQF) compliant. They may be further leveraged to disseminate AM specific curriculum

	tailored for the MSME segment. Government and industry partnership will be essential to ensure that technological infrastructure is made available at such centres.
Awareness	• Training on all the aspects of AM for all stakeholders is imperative. Further, to increase visibility into these technologies, relevant stakeholders could be engaged to promote thought leadership through Seminars, Conferences and workshops in confluence with domain experts.

5.2.2 Research and IP Creation

AM strategy should primarily focus on encouraging research and development in technologies encompassing TRL-0 to TRL-9, promoting competitive markets, and educating and training the next generation workforce. Dedicated R&D platforms should be established by private companies, and Government at academic institutes and laboratories. Indian R&D laboratories should also be nurtured and encouraged to work with industries to create Indian IP for the AM technologies including materials, machines, design software to provide specific technology solutions.

The following broad strategies for R&D in science and technology for AM could be followed:

Funding	• R&D efforts in AM should be focussed on creating indigenous IPR on materials, design, machines and software. These research efforts on Advanced Manufacturing could be supported by increase in grants-in-aid. Funding agencies could also have a dedicated budget head for AM and encourage consortium mode R&D. These funding agencies should also create roadmaps for short-term (3 years), mid-term (5 years) and long-term (10 years) for R&D as per market demand & job creation objectives and ensure the funds are disbursed accordingly. The fund release could also be based on performance and relevance to AM industry applications. Government support may also be extended

	through tax incentives and other benefits if the R&D projects are fully funded by private industry.
Centre of Excellence	• A Centre of Excellence dedicated to AM in electronics and photonics may be established, along with other relevant industries, at CMET- Pune. Other such Centre of Excellences may also be developed for advancement of AM in other sectors and these may also serve as common facilities. Partnerships with industry bodies like Additive Manufacturing Society of India (AMSI) will further aid addressal of industry needs on technology, design, software, materials, and machines.
IP Access Forum	• All intellectual property developed through public funded projects and applied research programmes for the AM Technology Advancement Plan to be made available on this platform such that the adoption of technology may be expedited. Specific mechanism for creation of such a forum and terms of access by the public could be devised in consultation with Academia and Industry. This forum may further act as a knowledge aggregating platform with all available industry reports, case studies, training and skill development courses, Government programmes and schemes, AM specific tenders, and RFPs.
International R&D Partnership	• While promoting emerging technologies like AM in the country, it would be appropriate to attract foreign leaders to set up their base in India and simultaneously promote Indian ancillary companies for strengthening their long-term value proposition. Bilateral and multilateral level Government-to-Government collaboration, also with institutes and industries should be encouraged for early success and long-term benefits, specially, in production of professional grade industrial AM systems, materials, specific design and optimisation software. India will thus be benefited from expertise developed in multiple global R&D hubs. The approach could be as follows: • ***USA and Europe:*** Collaboration with leading companies as core strategic allies on issues of global AM security.

	• ***Germany, Netherlands, UK and USA:*** Collaboration with global leaders in AM supply chain technologies. • ***Singapore, Japan, South Korea, Russia and South Africa:*** Collaboration in R&D hubs in specialized areas for developing niche market capabilities of AM. • ***Israel***: Institutional and industrial level collaboration on need-based requirements due to the country's significant production capability in industrial AM systems.

5.2.3 Supply Chain Development

Government financial support and private funding (venture capital, start-ups & accelerators) would be needed to promote the domestic AM eco-system and supply chains. To encourage integration of AM technologies across the domestic supply chain, the following measures are proposed:

Government Procurement Policies	Procurement policies of R&D organisations, Defence, Public Sectors, and Aerospace organisations should encourage purchase of AM machines and manufactured components & systems for their operations. These organisations could also prepare a 5-year road map for adoption of AM technology.
Preferential Market Access Policy	PMA policies may be structured to support local manufacturers who have availed support from certain technology upgradation programmes extended by Central and State governments, purchased technology from the IP Access Forum or whose operations are already aligned to the AM Technology Advancement Plan.
Incentives and Government Programmes	Few existing MSME schemes and programmes initiated by Central and state authorities to promote technology are in consonance with the principles of Additive Manufacturing Technologies. Schemes that extend support to MSME's for Technology upgradation should be promoted to augment adoption of AM by MSMEs. It is recommended to included AM

	technologies under schemes like: o Credit Linked Capital Subsidy Scheme for Technology Upgradation o Lean Manufacturing Competitiveness Scheme o Technology and Quality Upgradation Support to MSMEs Other incentives and support that the Government may extend to promote and accelerate adoption of AM technologies include: • State authorities may consider further incentives on Quality Certification charges to encourage purchase of AM Machinery. • A Single Window System may be developed to ensure expedited timelines for all major approvals like Factory Plan Approval, Factory License, CTO, CTE etc • Electricity tariff benefit could be extended to units with high power consumption requirements. • Plug and Play facilities could be provided by the government at a subsidized rental cost. • Development of Logistics and supporting infrastructure in case of production facilities situated in remote locations. • Long term Tax benefits to be considered for ease of availing loans to encourage reinvestment and scaling of production processes and technologies. • Graded incentive strategy to be considered to encourage local manufacturing by Start-ups & SMEs, and Foreign players. • A Dedicated programme may be initiated by the government to link AM with broader range of industries. • Financial support from Government and private funding (venture capital, start-ups & accelerators) to promote domestic AM eco-system and supply chains

	• Providing an attractive duty structure lowering the barriers to encourage AM technology, patents, materials, machineries etc. • Financial support to promote IPR creation to enhance capability of market breakthroughs. • Encouraging global AM leaders with latest technologies and foreign investments to Indian market. • Specific AM technology development platforms for facilitating commercialization and market development
Regional Industrial Innovation Clusters	Cluster-based agglomeration has been integral in improving regional economic performance and localizing supply chains. Creation of adequate infrastructure in a dedicated zone to facilitate setting up a smart manufacturing facility in the country Existing sector specific Industrial clusters/zones with adequate infrastructure and facilities suitable to Additive Manufacturing could be offered to attract global leaders and large domestic manufacturers to set up their operation. Dedicated facilities, like AMTZ, Vishakhapatnam, could be chosen for promoting AM hubs for specific sectors. Support from State Governments would be required to harness public and private sector investments to create and upgrade infrastructural facilities in industrial clusters for MSMEs and set up common facility centres. The facilities may also be equipped for testing, designing, tooling, training workforce and as a raw material depot.

6. CONCLUSIONS

Establishing a manufacturing eco-system in developing countries is always a challenge due to expensive physical infrastructure and production machineries and also lack of skilled manpower and sustainable supply chain. Additive manufacturing technology opens up new opportunities for economy and society by offering possibilities of cost effective and more flexible manufacturing eco-system. Small manufacturers can adapt to demand very quickly, the supply chain can be simplified by the industries by creating in-house AM printed end-use and spare parts. Though production remains modest, the economy of scale for the consumer market can, however, be achieved with advancement of this technology. AM technology offers an alternative path to the developing countries to overcome industrial competitiveness without substantial investment in physical infrastructure.

Major benefit of AM technology is in the domain of product design. It allows the production of any complex geometry without any tooling support. Moreover, the complexity does not impact the cost, unlike in case of conventional manufacturing. AM technology eliminates many restrictions of design for manufacture and assembly and opens a new realm of possibilities for new customized products at an affordable cost. The AM technology has a potential to revolutionize medical sector with bio-medical applications & manufacturing, also enhances the well-being of the citizens and improve energy efficiency in ground and air transportation.

Fast evolving AM technology is impacting global production processes with advancement of industrial AM, where significant breakthroughs are expected in near futures. The conventional manufacturing may completely replace small production domain, where mass customization holds the key. Foreign countries are aggressively promoting AM technology through significant financial support and other policy measures in order to capture global manufacturing space in emerging business opportunities. If India fails to cope up with the pace of AM innovation, it may lose control of technologies, which are being embedded in future strategic and commercial products.

The AM policy for India is imperative to keep pace with technology, identifying AM's likely path for development, and devising prudent strategy to navigate the path for future economic growth. However, the adoption and diffusion of this new technology is not instantaneous. With any new technology, new standards, knowledge, and infrastructure are required to facilitate its use.

AM technology has four verticals including materials, software, machines and service. India has a potential to create its dominance and leadership role in all the verticals due to its existing expertise. Innovation and R&D ecosystem engaging academia and industry participations would be important for realizing the fruits of this emerging technology.

Indian R&D laboratories could be nurtured to provide specific AM grade materials, through promoting existing research to technological readiness level (TRL) 4 to 9. Technology needs to be developed for 3D printer machine and printed product recycling. National strategy has to create an ecosystem for AM technology and embrace the latest developments of AM technology. Initiatives to be encouraged in private and public partnership to focus on developing applied design and engineering around levels 7 to 9 of TRL scale. The present accomplishment of process technology, design and engineering at TRL scale is inadequate and premature considering India's relative weakness in both the basic research at TRLs 1 to 3, and the development, demonstration and commercialization from TRLs 4 to 7.

India is a nascent market in the AM technology encompasses it's all verticals like metal, ceramic, biomedical, electronics. The market may still require a decade to match the developed economies. National strategy proposes to create a dedicated agency to spearhead the National Initiative for positioning India at the forefront of development and adoption of Additive Manufacturing Technologies. The Centre would act as an aggregator of knowledge and resources, and an accelerator for technology adoption and advancement.

The national strategy on Additive Manufacturing would thus focus on identifying present challenges and providing their immediate and long term solutions. The strategy identifies key areas which require immediate attention to support Indian AM sector. Actionable recommendations are provided to nurture Indian IP ecosystem in the area of materials and process technology, software & design and supply chain development. The requisite improvement required in academic institutions and research organisations is also proposed in the National Strategy to create awareness, skilled workforce and IP creation.

The National Strategy has also recommended the key steps to strengthen knowledgebase and infrastructure for standard and certification and robust legal framework to cope up with global competition. The strategy also identifies the key tax benefits, preferential market access specifically for start-ups/ SMEs, which may require overcoming the global completion. The requisite support for the manufacturers to mitigate issues like cyber security, export control etc. is also indentified.

A Centre of Excellence dedicated to AM in electronics and photonics is proposed to be established, along with other relevant industries, at CMET, Pune. Creation of other sector specific Centre of Excellences for advancement of AM as well as common facilities for serving Indian manufacturers are also proposed. Partnerships with industry bodies like Additive Manufacturing Society of India (AMSI) will be encouraged to address the industry needs effectively on technology, design, software, materials, and machines.

Annexure I

Major Global leaders in Additive Manufacturing

a. Materials

Sr. No.	Company details	Areas of Specialization and Operations	Technology Used	Geography of Operations
1.	Tekna, Canada	AM metal powder manufacturers **Powders:** Titanium Alloys, Nickel Alloys, Aluminium Alloys, Tungsten, Tantalum, Molybdenum	Plasma Technology Metal Powder System and Powder Manufacturer	France, China, South Korea, Japan, South Africa, Australia, New Zealand, Singapore, Taiwan, India.
2.	GKN Hoeganaes, Germany	AM Metal powder manufacturers **Powders:** Aluminium alloys, Low alloy steels, Inconel alloys, Titanium alloys	Plasma Technology Metal Powder System and Powder Manufacturer	South America, North America, Europe, Asia Pacific, Africa.
3.	Hoganas, Sweden	AM Metal powder manufacturers **Powders:** Nickel alloys, Cobalt alloys, Iron alloys	Gas Atomised powders	United States of America, United Kingdom, Europe, India, Indonesia, South Korea
4.	Praxair Surface Technologies, USA	AM Metal powder manufacturers **Powders:** Cobalt alloys, Iron alloys, Nickel alloys, Titanium alloys	-	United States, Europe, Singapore, South Korea, United Kingdom, Canada, Japan, China, Brazil. India
5.	Sandvik AB, Sweden	AM Metal powder manufacturers **Powders:** Titanium alloys, tool steel, stainless steel, nickel based super alloys, Copper alloys	Gas Atomised powders	Sweden**,** United States, Europe, United Kingdom, India
6.	Carpenter Additive, USA	AM Metal powder manufacturers **Powders:** Titanium alloys, tool steel, stainless steel, nickel based super alloys, Copper alloys, Cobalt alloys, Iron alloys, Refractory metals, scalmalloy	Gas Atomisation, Water Atomisation, Plasma atomisation, Centrifugal atomisation.	United States, Europe, United Kingdom, Singapore, Canada
7.	Pyrogenesis Additive, Canada	AM Metal powder manufacturers **Powders:** Titanium alloys, tool steel, stainless steel, nickel based super alloys,	Plasma atomisation,	Canada

b. Machines

Sr. No.	Company details	Areas of Specialization and Operations	Technology Used	Geography of Operations
1.	EOS GmbH, Germany	Metal Additive Manufacturing Machine Manufacturer.	Powder bed fusion	Germany, USA, Asia - Pacific
2.	Renishaw,United Kingdom	Metal Additive Manufacturing Machine Manufacturer.	Powder bed fusion	United Kingdom, Europe, USA, Asia-Pacific
3.	GE Additive, USA	Laser and electron beam based Metal Additive Manufacturing Machine Manufacturer.	Powder bed fusion	United Kingdom, Europe, Sweden, USA, Asia-Pacific
4.	SLM Solutions AG, Germany	Metal Additive Manufacturing Machine Manufacturer.	Powder bed fusion	Europe, United Kingdom, Europe, USA, Israel, Russia, Asia-Pacific
5.	Voxeljet AG, Germany	3D Sand Printing, Machine Manufacturer.	3D Sand Printing	Europe, United Kingdom, USA, Israel, Russia, Asia-Pacific
6.	ExOne, USA	3D Sand Printing, Machine Manufacturer.	3D Sand Printing	USA, Europe, United Kingdom, Israel, Russia, Asia-Pacific
7.	Optomec, USA	Laser Metal Deposition Machine and 3D Printing of Electronics Machine Manufacturer.	3D Bioprinting Deposition,	USA, Europe, United Kingdom, Middle East, Asia-Pacific
8.	RPM Innovations, USA	Laser Metal Deposition Machine Manufacturer.	Laser Metal Deposition,	USA
9.	Sciaky Inc., USA	Electron Beam Additive Manufacturing, Machine Manufacturer.	Electron Beam Additive Manufacturing	USA, Europe, Asia-Pacific
10.	Additive Industries, Netherlands	Metal Additive Manufacturing Machine Manufacturer.	Powder bed fusion	Europe, USA, Asia – Pacific, United Kingdom
11.	Trumpf, Germany	Metal Additive Manufacturing Machine Manufacturer.	Powder bed fusion and Laser Metal Deposition	Europe, USA, Asia – Pacific, United Kingdom, Mexico
12.	Cobod, Denmark	3D Construction Printing Machine Manufacturer	3D Construction Printing	Europe
13.	Hamilton Labs, Singapore	3D Construction Printing Machine Manufacturer.	3D Construction Printing	Singapore, India
14.	Stratasys, USA	Plastic 3D Printing Machine Manufacturer.	Fused Deposition Modelling &Polyjet Printing	USA, Europe, Asia-Pacific, Mexico, Middle East

c. Software

Sr. No.	Company details	Areas of Specialization and Operations	Technology Used	Geography of Operations
1.	Materialise, Belgium.		Magics, Mimics, 3-matic, Streamics, and other software products	USA, Asia-Pacific
2.	Autodesk NETFAB, USA		3D CAD Software	USA, Asia-Pacific, Europe
3.	Altair 3D Matic, USA		3D Matic optimising Software	USA, Asia-Pacific, Europe, Mexico, Egypt, Middle East, Mexico

d. Services

Sr. No.	Company details	Areas of Specialization and Operations	Technology Used	Geography of Operations
1.	Protolabs, USA	-	Plastic and Metal 3D Printing, Injection Moulding, Machining	USA, United Kingdom, Japan, Europe
2.	3T Additive Manufacturing, United Kingdom	-	Plastic and Metal 3D Printing	United Kingdom
3.	3D Hubs, Netherlands	-	Plastic and Metal 3D Printing, Injection Moulding, Machining	Netherlands, Germany, United Kingdom, Europe, USA
4.	Star Rapid, China	-	Plastic and Metal 3D Printing	United Kingdom, USA, Asia Pacific, Europe
5.	Agile Manufacturing Inc. Canada	-	Plastic and Metal 3D Printing	Canada

Annexure II

Innovation Road Map

Focus Area	Consolidated Objective	Consolidated Impact Description
Design Design methods and tools are essential to design AM parts like conventional manufacturing methods (Cast or machined part)	• Enable strong and smart design tools. • Enable Design for Additive Manufacturing (DfAM)	• Streaming process of design with reduced cycle time, higher functionality products. • Apply design for additive manufacturing for specific applications.
Material Development of advanced materials for industrial applications such as defence, aerospace, automotive, biomedical, industrial applications, electronics etc.	• Describe standard AM Material requirements. • Set up vendor qualification & encourage AM material source expansion. • Produce AM materials. • Develop materials qualification and certification	• Set up the AM material development actions to increase the component performance. • Set up a single source of material, process and functionality documents. Enhance material research to provide quality of final AM components.
Process Need for technological advancement in faster, accurate, high resolution, large format-built capacity AM machines.	• Develop stable & strong AM processes. Develop process control. • Develop open platform equipment • Develop new AM process capabilities.	• Facilitate the wider application of AM through process control and machine robustness. • Establish processes to enhance the applications of AM for various sectors.
Value Chain Need for technological improvements in AM value chain economy, lead times and market launch timing	• Develop cost models and tools. • Establish qualification and certification for AM system and components. • Develop open platform equipment. Develop new AM process capabilities.	• Identify when, where and how to use AM. • Installation of AM machines across various industry segments. • Setup up business plans to ensure the continuous • Integration of AM technology into the present supply chain

GLOSSARY

S.No.	List of Words	Description
1.	3D model	three-dimensional model
2.	ABS	Acrylonitrile Butadiene Styrene
3.	AM	Additive Manufacturing
4.	AMTZ, Vishakhapatnam	Andhra Pradesh MedTech Zone, Vishakhapatnam
5.	ASEAN	Association of South East Asian Nations
6.	ASTM	American Society for Testing and Materials
7.	BS-VI norms	Bharat Stage- VI norms
8.	CAD model	Computer Aided Design
9.	CAM	Computer Aided Manufacturing
10.	CAGR	Compound Annual Growth Rate
11.	CMT	Cold Metal Transfer
12.	CNC	Computer Numerical Control
13.	CSR	Corporate Social Responsibility
14.	CTE	Comprehensive Tax Evaluation
15.	CTO	Chief Tax Officer
16.	DED	Direct Energy Deposition
17.	DfAM	Design for additive manufacturing
18.	DMLM	Direct Metal Laser Melting
19.	DMLS	Direct Metal Laser Sintering
20.	DRDO	Defence Research and Development Organisation
21.	FDM	Fused deposition modelling
22.	GDP	Gross Domestic Product
23.	HIP	hot isostatic pressing
24.	IPR	Intellectual Property Rights
25.	IIT	Indian Institute of Technology
26.	LENS	Laser Engineered Net Shaping
27.	LOM	Laminated object manufacturing
28.	MJM	Multi-jet modelling
29.	MSME	Micro, Small & Medium Enterprises
30.	NDE	Non-Destructive Evaluation
31.	NDT	Non-Destructive Testing
32.	NSQF	National Skill Qualification Framework
33.	OEMs	Original Equipment Manufacturers
34.	OFB	Ordnance Factory Board
35.	PC	Poly Carbonate
36.	PCB	Printed Circuit Board
37.	PLA	Poly Lactic Acid
38.	PLD	Pulsed Laser Deposition
39.	PPP	Public Private Partnership
40.	PVA	Poly Vinyl Alcohol
41.	SEBM	Selective Electron Beam Melting
42.	SHS	selective heat sintering
43.	SMD	Surface Mount Device
44.	SLM	Selective Laser Melting
45.	STEM	Science, Technology, Engineering and Mathematics
46.	STED	Simulated Emission Depletion
47.	STL	Stereolithography
48.	SMT	Surface-Mount Technology
49.	TIG	Tungsten Inert Gas (TIG) welding
50.	TRL	Technology Readiness Level
51.	UC	ultrasonic consolidation