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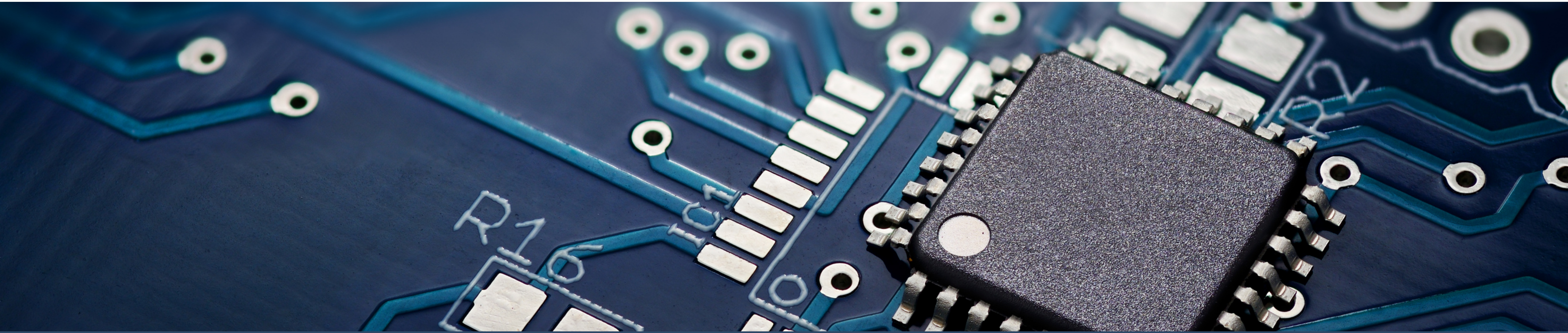
India's Semiconductor Ecosystem: A SWOT Analysis

Takshashila Discussion SlideDoc
August 2021
v1.0



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Suggested citation:

Tripathy et al, "India's Semiconductor Ecosystem: A SWOT Analysis", Takshashila Discussion SlideDoc 2021-02, August 2021

Contents

List of Acronyms

5G: 5th Generation
AI: Artificial Intelligence
ATMP: Assembly, Testing, Marking & Packaging
CHIPS: Creating Helpful Incentives to Produce Semiconductors
CMOS: Complementary Metal–Oxide–Semiconductor
CoE: Center of Excellence
COVID-19: Coronavirus Pandemic of 2019-21
DRDO: Defence Research and Development Organisation
EDA: Electronic Design Automation
EE: Electrical Engineering
EMC2.0: Modified Electronic Manufacturing Cluster
EOI: Expression of Interest
EU: European Union
FTA: Free Trade Agreement
GDP: Gross Domestic Product
IC: Integrated Circuit
IDM: Integrated Device Manufacturer
IEEE: Institute of Electrical and Electronics Engineers
IISc: Indian Institute of Science
IIT: Indian Institute of Technology
IoT: Internet of Things
IP: Intellectual Property
M.Tech: Masters in Technology
ML: Machine Learning
MNC: Multinational Corporation
MOSIS: Metal Oxide Semiconductor Implementation System
MWh: Mega watt-hour
NIT: National Institute of Technology
ODM: Original Device Manufacturer
OEM: Original Equipment Manufacturer
OSAT: Outsourced Assembly & Testing
PhD: Doctor of Philosophy
PLI: Production Linked Incentive
PPP: Public Private Partnership
R&D: Research and Development
RISC: Reduced Instruction Set Computer
SCL: Semiconductor Laboratory
SITAR: Society for Integrated Circuit Technology & Applied Research
SPECS: Scheme for Promotion of special Electronics & Semiconductors
STEM: Science Technology Engineering Mathematics
US: United States
VC: Venture Capital
VLSI: Very Large Scale Integration

Executive Summary

Technological, geoeconomic, and geopolitical imperatives underlie recent attempts by nation-states to revisit their semiconductor industry policies. India too is in the midst of rolling out several incentives (Appendix A) to safeguard its economic and strategic interests.

This document takes a step back and zooms in on the strengths, weaknesses, opportunities, and threats of India's semiconductor ecosystem.

We find that India's primary strength lies in its vibrant integrated circuit (IC) design ecosystem with a highly experienced talent pool. However, weak research & development (R&D) focus, prohibitive costs of acquiring intellectual property (IP), and limited start-up capital have inhibited the potential of local design houses.

In semiconductor manufacturing, misplaced policies prioritising capital-intensive leading-edge nodes have led to several false starts. The real opportunity for India lies in trailing edge node fabs and specialty fabs.

Finally, in the absence of backward linkages with fabrication plants or forward linkages with Original Device Manufacturers (ODMs) or Original Equipment Manufacturers (OEMs), doing business in the Assembly, Testing, Marking & Packaging (ATMP) segment in India becomes prohibitively expensive.

We recommend that India should strive to create a world-class fabless ecosystem by facilitating domestic design IP creation. The ATMP market is gradually becoming R&D intensive and the demand for product conceptualisation skills is increasing. India will have to align its skilling policies in alignment with the industry. Further, we suggest that India "looks outward" and leverages consortiums like the Quad to pool in resources, jointly invest, and conduct trade to obtain critical access to materials, technological know-how, and markets for semiconductors.

Why Semiconductors Matter

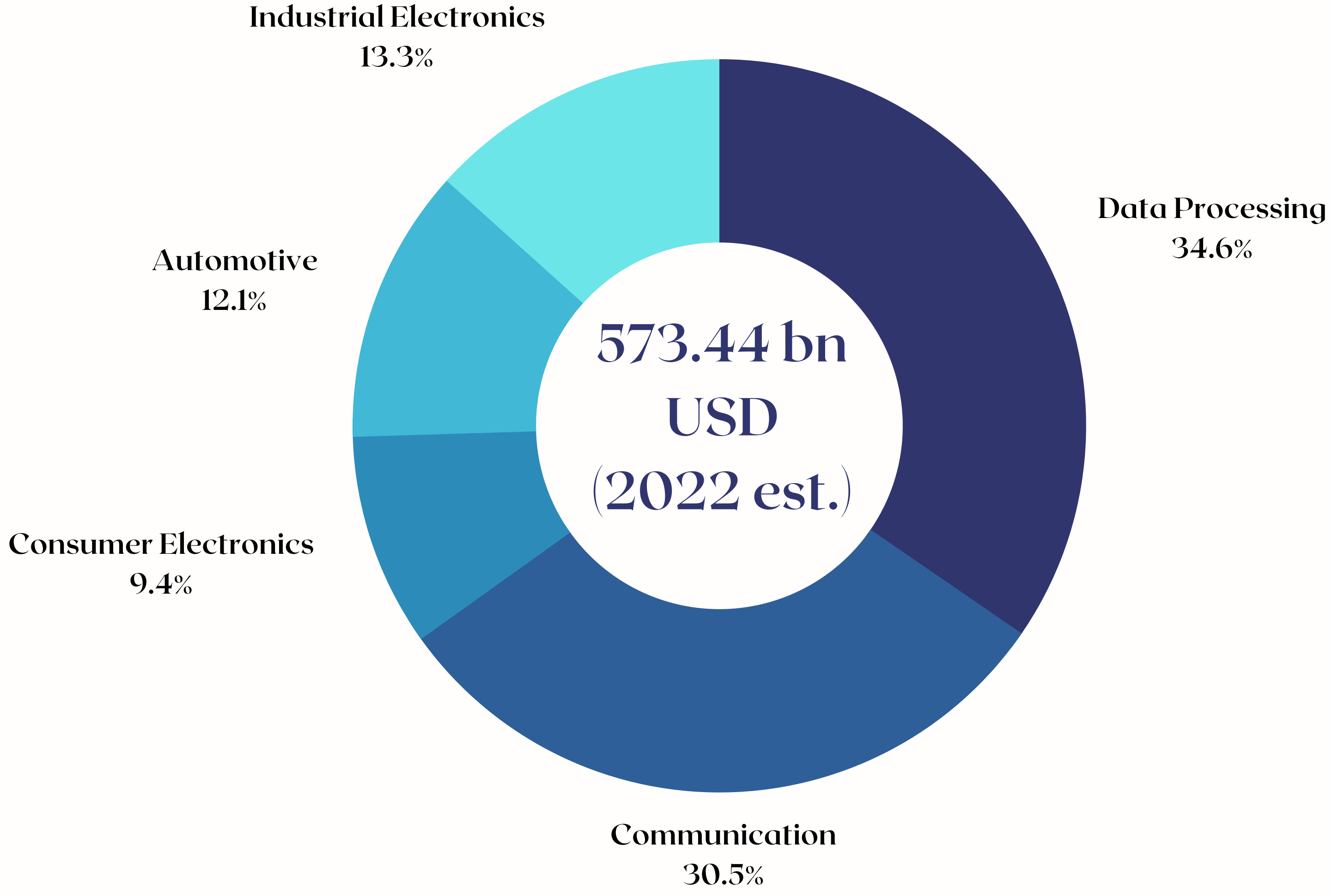
Technological Importance

Semiconductors are the “brains” of modern-day electronics spanning consumer products like smartphones and smart TVs to more sophisticated equipment used in industrial applications, defence & aerospace. They also act as a foundational technology for advancements in other critical & emerging technologies. For example:

1. Artificial Intelligence (AI) applications require new semiconductor architectures with faster data movement between processor and memory. This architectural change demands a move away from general-purpose technology to specialized processors (referred to as AI chips).
2. Advancements in the automotive industry covering electric vehicles, autonomous driving & stringent safety standards have led to a surge in demand for microcontrollers, sensors & memory chips.
3. The 5G communication revolution relies on a new breed of baseband chips that can operate over a wider frequency range.

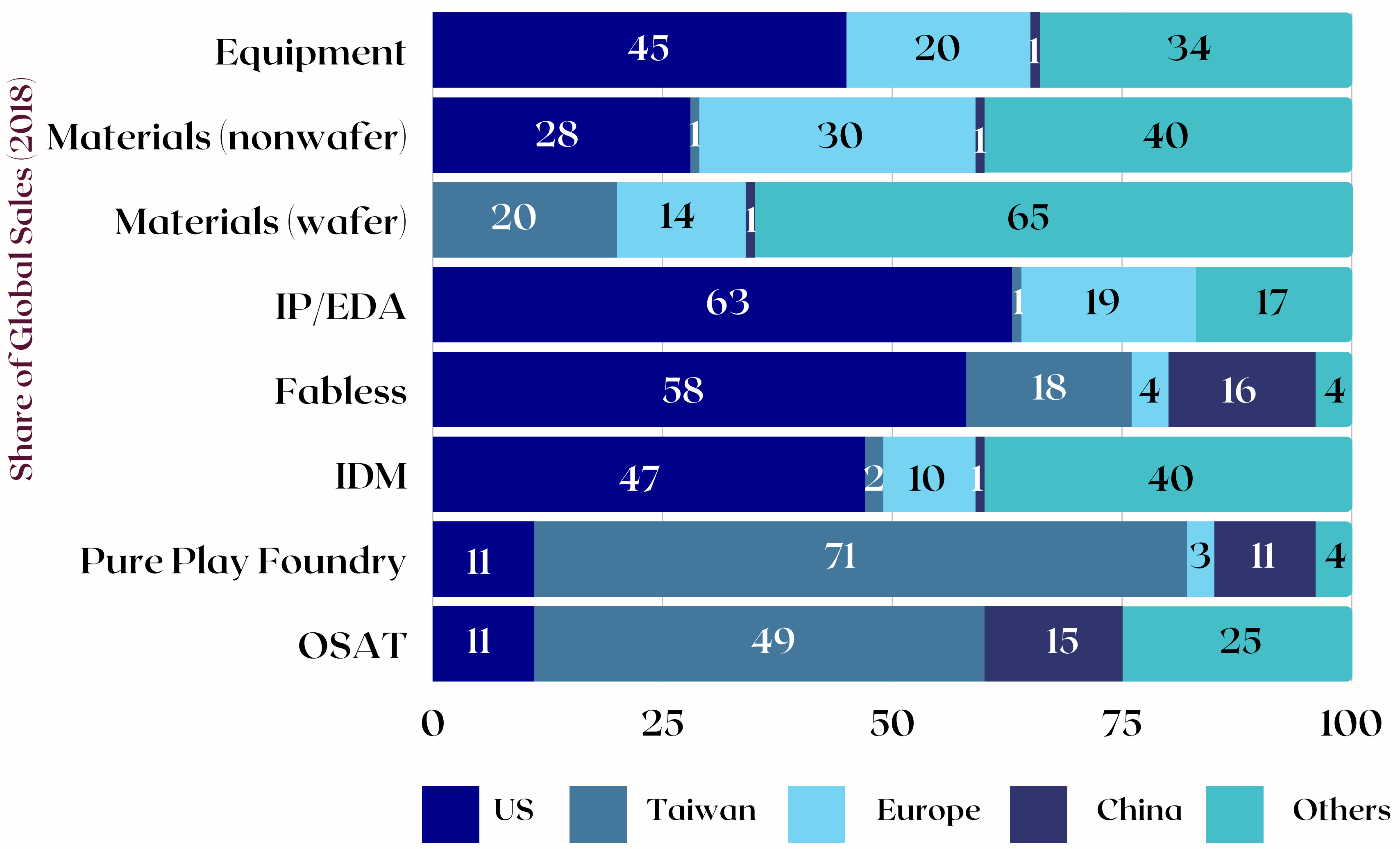
Factoring this technological significance, any national technology policy needs to put semiconductors at the front and centre. [1]

Fig 1: Semiconductors are indispensable for modern-day life [2]



Why Semiconductors Matter

Fig 2: The semiconductor supply chain is globally integrated yet highly vulnerable to geopolitical tensions [3]



Geopolitical Importance

The economics of the semiconductor supply chain makes it a viable geopolitical tool. Manufacturing facilities, equipment, and materials are concentrated in a handful of countries. Consequently, nation-states can deny their competitors access to parts of this supply chain in furtherance of their geopolitical objectives.

This is why semiconductors have become a major front in the US-China trade war. Trade bans and export controls are increasingly been used by the US to exhibit power & thwart China's attempts to achieve self-sufficiency in semiconductors. Moreover, Taiwan remains the most significant bottleneck in the global semiconductor supply chain. Cyberattacks and corporate espionage by China on Taiwanese semiconductor companies have increased. A hostile Chinese takeover can no longer be dismissed as a remote possibility.

The geopolitical risks for disruption are too high to ignore. [1]

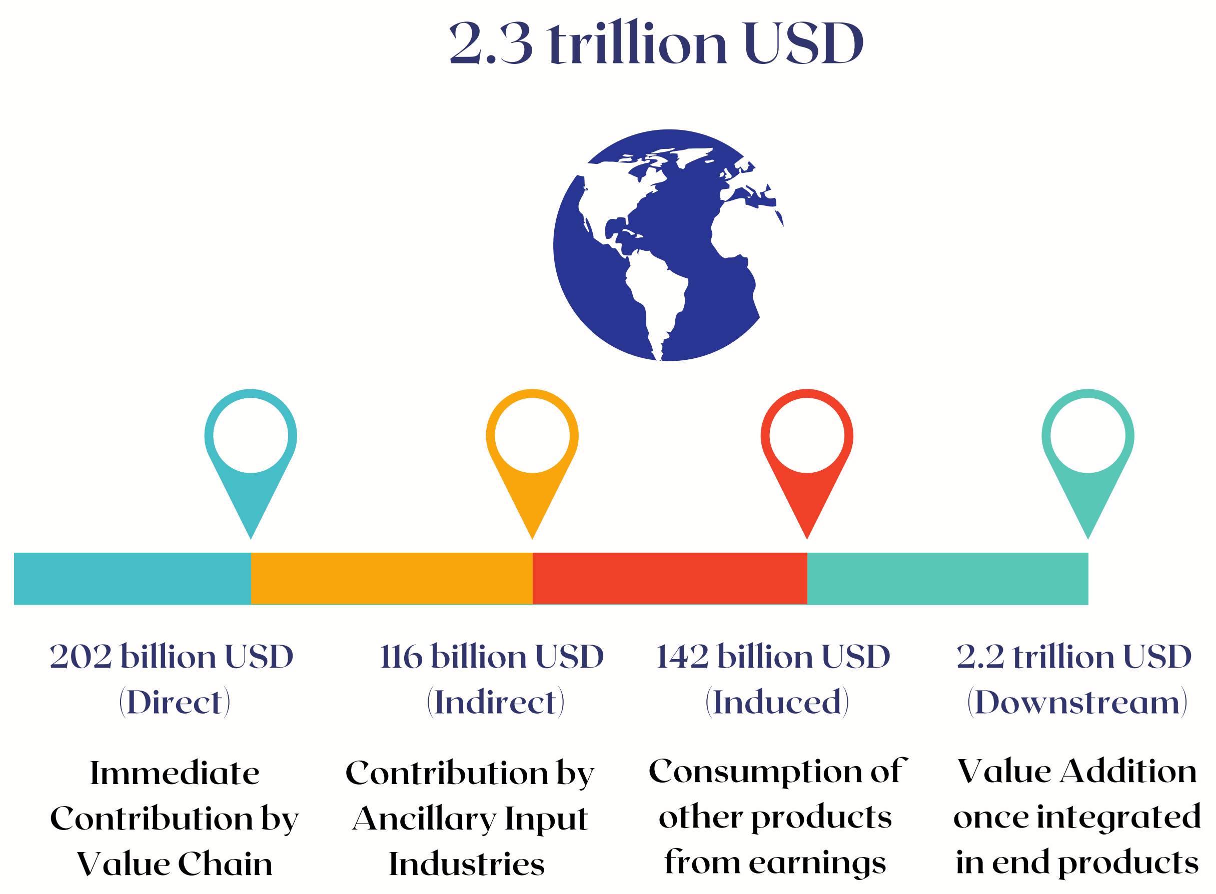
Why Semiconductors Matter

Economic Importance

Today, the semiconductor industry contributes to nearly $2.3 trillion of the world's GDP [4]. This includes both upstream & downstream contributions to economic value. Over the past few decades, the industry succeeded because of globalisation — countries specialised in specific parts of the supply chain, relying on trade by comparative advantage to drive cost efficiencies. Hypothetically, had countries relied on "self-sufficient" local supply chains, it would have resulted in at least an additional 1 trillion USD in upfront investment and adversely impacted the affordability of semiconductors[5].

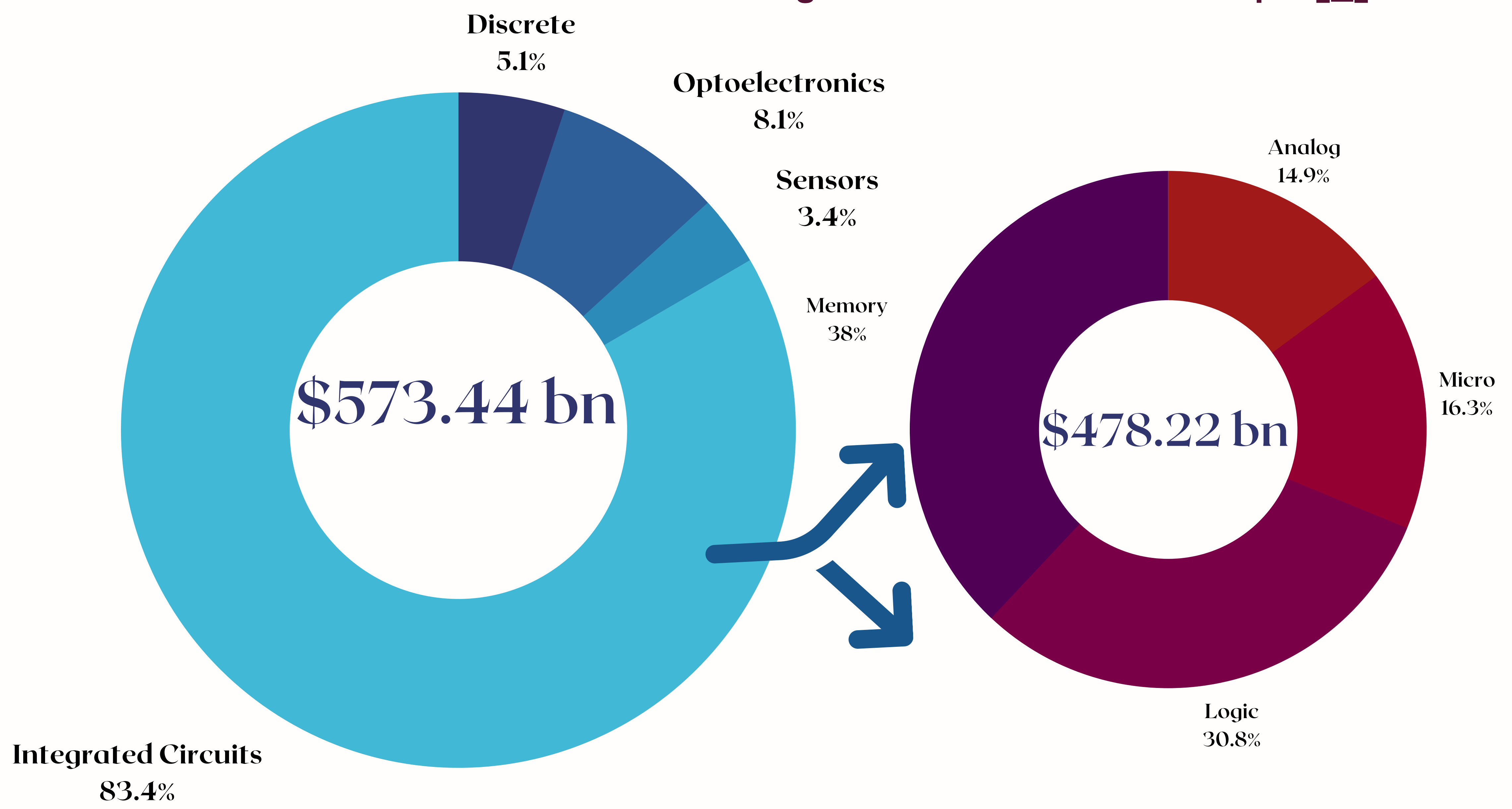
However, these efficiencies have come at the cost of resilience. There remain several choke points in the supply chain. For example: As local shutdowns continued during the COVID-19 pandemic, a semiconductor shortage crippled the automotive industry and threatened to wipe off nearly $60 billion in revenue in a single year [6]. Hence, there is a need to diversify partnerships and build supply chain resilience for safeguarding economic interests.

Fig 3: Contribution of Semiconductors to World GDP [4]



Semiconductor Market 2022

Fig 4: Semiconductor Market Split [2]



Semiconductors can broadly be divided into four categories - integrated circuits (eg. a Qualcomm Snapdragon chip), Optoelectronics (eg. light-emitting diodes), discrete components (eg. rectifiers), and sensors (eg. CMOS image sensors for cameras). Of the four, integrated circuits (ICs) account for 83 percent of the total economic value.

These ICs are further divided into four categories — memory, logic, analog, and micro. Given their overwhelming importance, this document zooms in on India's strengths, weaknesses, opportunities, and threats in the production of ICs.

Semiconductor IC Value Chain

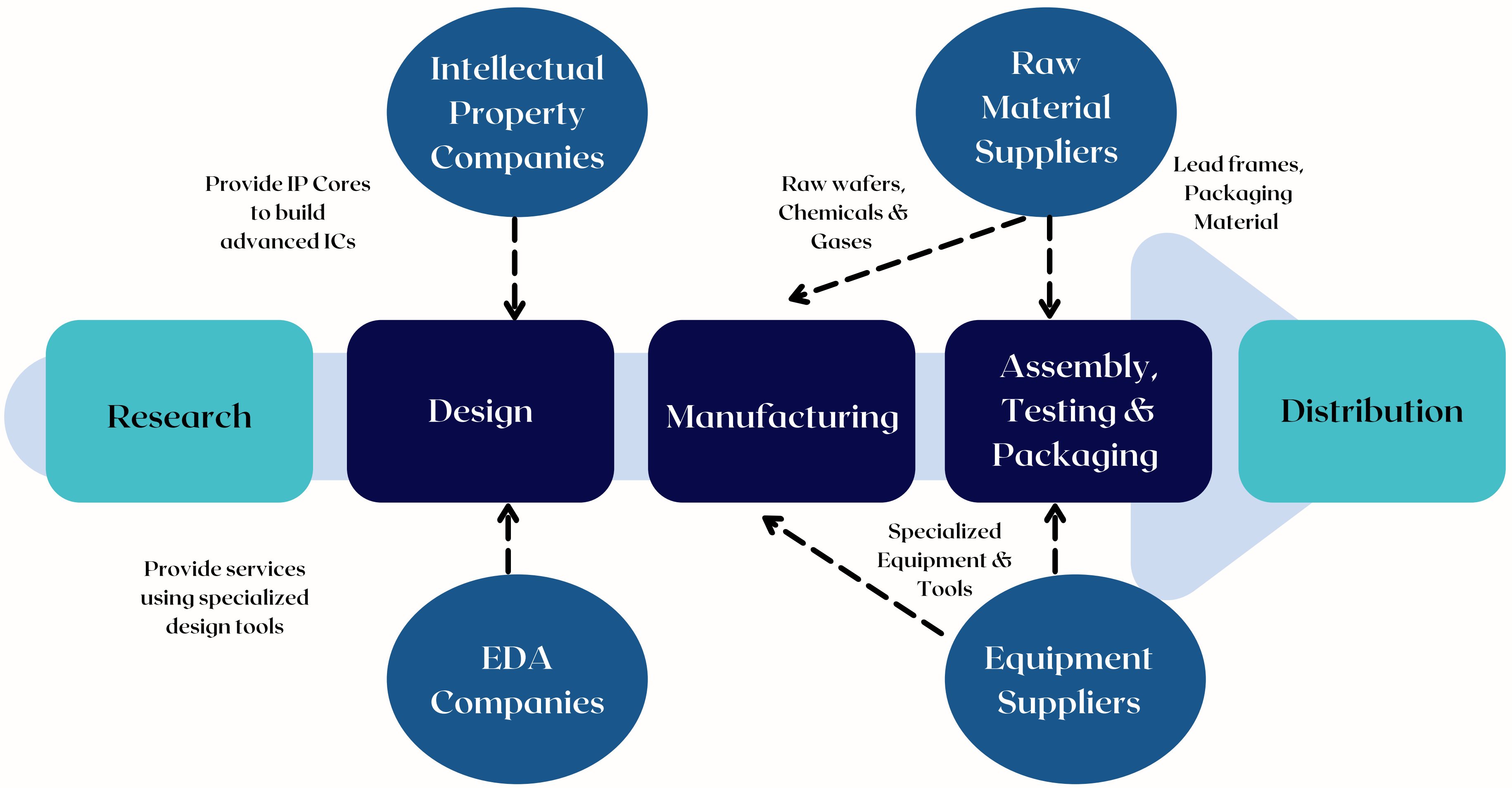


Fig 5: Semiconductor Value Chain [7]

Producing a semiconductor IC is a complex process. It can broadly be divided into five functional stages.

Research & Development:
Pre-production efforts to increase processing capability & speed at a reduced cost. The focus is on surpassing the physical limits of semiconductor materials. Highly capital intensive (~25% of sales value).

Design:
Start of production. Highly skill-intensive, access to design software & IP blocks. R&D costs are high in this stage as well.

Manufacturing:
Highly capital intensive, access to manufacturing equipment, chemicals & wafer facilities, need to constantly upgrade facilities as per technological advancement.

Assembly & Testing:
Highly labour-intensive, less reliant on tech, high volume low margins, could be proved redundant by fabs creating wafer-level packaging. End of production.

Distribution:
Finished semiconductors are sold to Original Equipment Manufacturers (OEMs) for use in electronic goods. Needs an efficient logistics network.

Fig 6: A Typical Semiconductor Production Journey [8]

Given the complexity and resultant costs of IC production, no country is self-sufficient in semiconductors. Instead, semiconductor powers specialise in certain parts of the value chain.

A typical semiconductor production process spans 4+ countries, 3+ trips around the world, 25000 miles travelled & 12 days in transit [7].

Both manufacturing & assembly are highly concentrated in East Asia - vulnerable to political risks & natural disasters.

Semiconductor IC Landscape in India: Some Key Features

A large domestic market	Highly dependent on imports	A vibrant IC design ecosystem	A few state-led R&D IC manufacturing facilities	Limited presence in the Assembly & Test space
Estimated annual consumption of semiconductors worth 52.58 billion USD in India (2020) [9].	Electronics imports worth 49 billion USD (2019) mostly from countries such as US, Japan, China & Taiwan [10].	Value add worth 33.1 billion USD in 2020 by design houses based in India [11]. Contribution by MNC R&D & local design startups.	SCL, SITAR & IIT Bombay. Mature nodes. Mainly used for R&D in defense & space. Private sector missing [12].	Prominent ones are SPEL Semiconductor, ChipTest Engineering & Tessolve Semiconductor [12].

SWOT Analysis of India's Semiconductor IC Ecosystem

As the previous slide suggests, India and Indians play an important role in the global semiconductor supply chain. To understand this role better, this section analyses India's strengths & weaknesses (factors internal to ecosystem) and opportunities & threats (factors external to ecosystem) across the 3 main stages of semiconductor production i.e. design, manufacturing, and assembly, testing & packaging services. This analysis considers R&D as a critical input in both design & ATMP stages.

Semiconductor IC Design in India

Over the years, many global semiconductor giants have established their chip development R&D centers in India. This has built a critical mass of talent in semiconductor design and a vibrant domestic design services market. However, indigenous design IP creation is muted.

Semiconductor IC Design SWOT

Availability of Skilled Workforce

- Most of the major semiconductor companies (TI, Broadcom, Intel, Qualcomm, Western Digital, Samsung & Huawei) have their fabless Intellectual Property (IP) & System-on-Chip (SoC) design houses in India [13].
- Nearly 3000 chips are designed annually employing 30,000 engineers [14].
- Several local design service companies working in networking, microprocessors, analog chip design and memory subsystems [15].

Exposure to Full Design Cycle

- Exposure to cutting-edge design innovation for advancing yield & performance of chips. For example, power optimization (AMD), advanced die stacking (Intel), AI & ML, and 5G Communication (Qualcomm) [16].
- A surge in projects in chip development (even in leading-edge technology nodes) as compared to derivative chip design a few years ago.

Steady Talent Flow from Universities

- Annually, nearly 1.9 million students enroll in computer science, electronics & electrical engineering streams across India [17].
- IIT, NIT & IISc students are trained in VLSI design & related areas through the Special Manpower Development Programme (SMDP) and Technical Education Quality Improvement Program (TEQIP) of the Government of India [18].
- There is a robust private market of VLSI training houses outside the formal education system [19].

Strength

Weakness

Opportunity

Threat

Semiconductor IC Design SWOT

Poor Linkage with Fabs

- Since semiconductor tech especially at leading-edge nodes is fast evolving, linkages between design centers and fabs are a must to cut short the time for testing, validation, and go to market.
- Fabs cannot be expected to keep dead nodes alive for low volumes. Design firms don't want to be in a situation where the production of their designs is not economical for fabs.

Weak R&D Focus

- India (government + private) invests 0.65% of its GDP on R&D (across sectors) in comparison to China (2.4%), the United States (2.85%), and Europe (2.18%).
- The business sector's contribution to total Gross Expenditure on total R&D is 37% (compared to 68% in the top 10 economies globally).
- Share of total R&D personnel by the business sector is 30% & 34 % respectively (compared to 58 % & 53 % in top 10 economies globally) [20].

Muted Investor Interest

- Semiconductor startups have raised ~1.3 billion USD globally over the past 5 years [21] but VC & strategic investments in India have been muted.
- Can be attributed to market volatilities, high sunk costs (of Electronic Design Automation tool licenses), limited demand for indigenous ICs by domestic strategic sectors, and inadequate product conceptualisation knowledge [22].

Strength
Weakness
Opportunity
Threat

Semiconductor IC Design SWOT

Strength

Weakness

Opportunity

Threat

Poor IP Regime

- Total patent-pending applications from India stand at around 2.2 million (compared to ~11 million from the US & China).
- Even within that, Indian residents' share in total patents applications filed in the country is 36% (compared to 62% in the top 10 economies globally) [20].
- Can be attributed to low domestic awareness around filing, inadequate cross-sharing agreements for data & harmonization of litigation parameters with other countries.
- The cost of acquiring IP in-house for semiconductor design is quite high (~2 million USD) and may be unaffordable for individuals or early-stage startups [3].
- Multi-project wafer (MPW) services by foundries (like MOSIS) that allow design units to share mask and wafer resources for prototyping & verification in small quantities are missing in India [24].
- India's acceptance rate of research publications in IEEE is ~4.5% (compared to ~36% in the US). This indicates that poor research quality may be a contributing factor to low IP creation [25].

Average Talent Management

- Though a high volume of STEM graduates pass out annually, infrastructure for L&D in design (i.e. research labs with industry linkages) is inadequate.
- India doesn't produce enough M.Tech or PhDs in semiconductor-related fields (a mere 8% of graduates). Critically linked to career prospects & remuneration offered [25]. This is one of the reasons for low IP creation.

Semiconductor IC Design SWOT

Strength

Weakness

Opportunity

Threat

High Potential of India's Diaspora

- During the two decades following 1985, nearly 8000 Indian citizens earned doctorates in engineering (all-inclusive; not limited to streams relevant to semiconductor design) in the US.
- Most Indians stayed for at least five years after the award of their doctorates, a number that has remained fairly constant near 90% per annum since the early 1990s [26].
- Better opportunities, a growing economy, and improvement in lifestyles can incentivise a 'brain gain' (as seen in the Thousand Talents Program in China) [27].

Rising Geo-political Tensions

- Amidst the escalated conflicts between the US & China, suspicion around security vulnerabilities in imported IC designs & theft of exported IP has led to project bans & contract restrictions for many suppliers (ex: Huawei) and cancellation of acquisitions (ex: Imagination Technologies). Companies are looking to diversify their centres [28].
- Factoring the quantum of IP produced for global semiconductor companies by Indians, this respect & trust commanded by Indian firms can make them attractive as partners for scalability.

Semiconductor IC Design SWOT

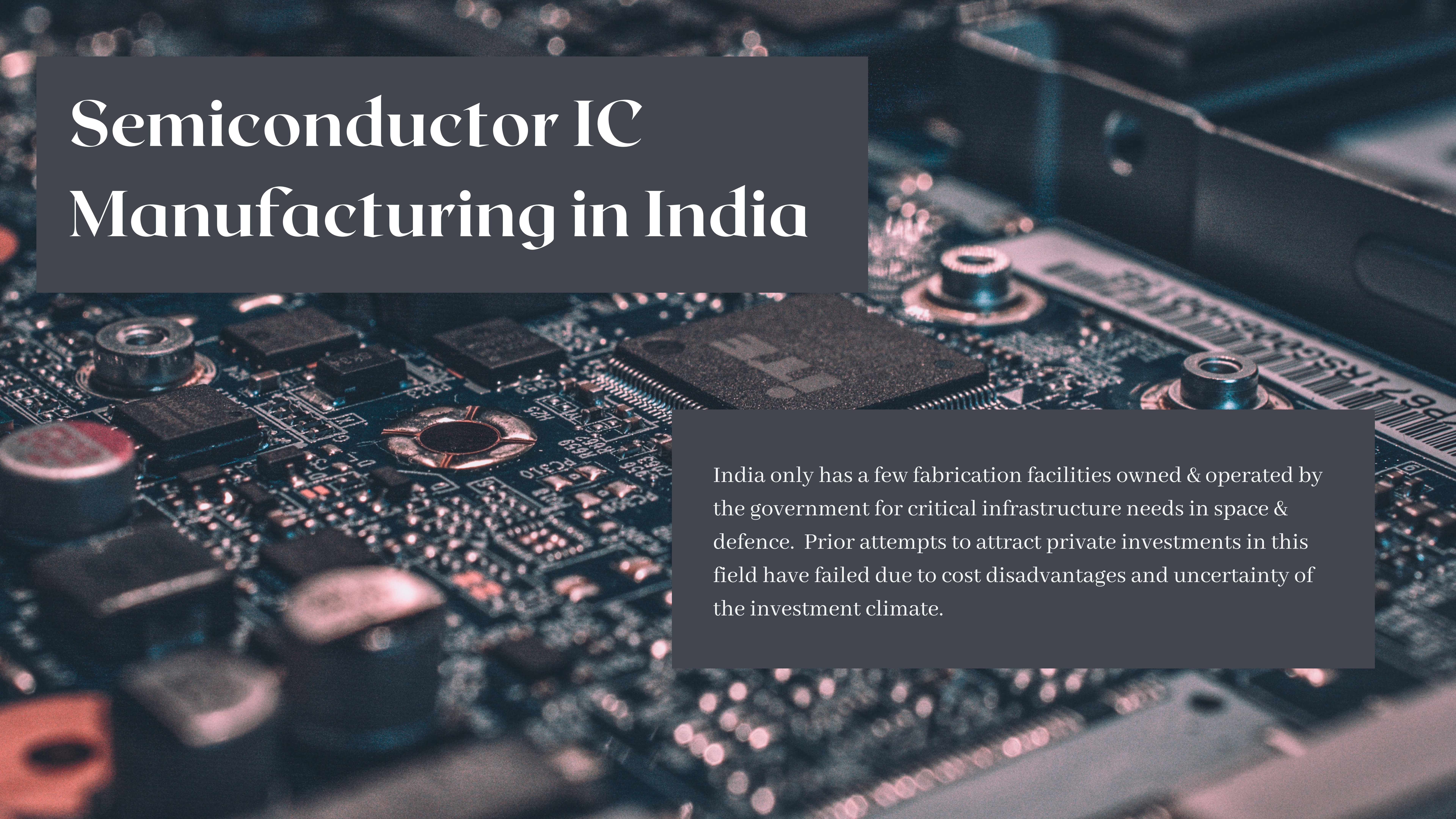
Emerging Tech	• Areas like cloud computing, machine learning, connected cars/automotive, IoT and AI will continue to drive the need for a new breed of chips gives an opportunity to shift focus from improving silicon performance to increasing learning ability & decreasing power usage. Design is not anymore a losing game against Intel's x86.
Significant Local Demand	• Innovations in chip design to meet local needs (such as dealing with power fluctuations & limited signal transmission range in telecom) [29] can create demand in India and emerging economies (such as Latin America & Africa). • The large potential consumer base for white goods (domestic & industrial appliances) and automotive. • New Government-industry initiatives such as the Semiconductor Fabless Accelerator Lab (SFAL) in Karnataka are reducing entry barriers for fabless companies [30].
Eroding Cost Competitiveness	• India enjoys a significant cost advantage in design services as compared to the US, Europe, or Japan. This is attributed to the competitive salaries of semiconductor design professionals and affordable Grade A office space rentals. • High costs of electricity & difficulties in raising capital in India can hamper this strength [25].

Strength

Weakness

Opportunity

Threat



Semiconductor IC Manufacturing in India

India only has a few fabrication facilities owned & operated by the government for critical infrastructure needs in space & defence. Prior attempts to attract private investments in this field have failed due to cost disadvantages and uncertainty of the investment climate.

Semiconductor IC Manufacturing SWOT

Strength

Weakness

Opportunity

Threat

Strength	**A Robust Fabless Ecosystem**	• India has a thriving design market (fabless ecosystem) contributing 33.1 billion USD annually in value addition. • Indigenous designs on RISC-V (open-source microprocessor architecture) are scalable & adaptable [31]. • This ecosystem provides a strong incentive for the formation of a Pure-Play foundry in India.
Strength	**Nascent Manufacturing Capabilities**	• Three government-owned modest fab facilities in India: SITAR in Bengaluru and Gallium Arsenide Enabling Technology Centre (GAETEC) in Hyderabad (both under DRDO) and the Semi-Conductor Laboratory (SCL) in Chandigarh (under the Department of Space). • The government has supported a Gallium Nitride facility at the Indian Institute of Science (IISc), Bangalore.
Strength, Weakness	**Policy Priorities**	• Recent government schemes (such as PLI & EMC2.0) are flexible and commit upfront funding (change from the former reimbursement model) [32]. • Apart from the EOI committing 1 billion USD investment for any fab manufacturing set up in India, the state hasn't laid out attract any concrete policy to attract wafer manufacturers. The focus on leading-edge nodes (~5 nm) is also misplaced given that richer countries are opting for more aggressive industrial policy measures [33].

Semiconductor IC Manufacturing SWOT

Strength

Weakness

Opportunity

Threat

Average Raw Material Availability

- India's expanding specialty chemical sector can be used for manufacturing chemicals (esp. photoresists).
- Inadequate availability of large quantities of pure water (~8 million gallons per day), uninterrupted power (~169 MWh), pollution-free environment (controlling for temperature & humidity), logistics, and waste disposal
- Sand used for growing wafers has to be clean & pure (not available in India). Either has to be imported or additional shop floor for cleaning sand has to be set up. Could leverage experience in managing electric arc furnaces in steel plants for silicon crystal growth (up to 18 inches diameter) [34].

Capital Inadequacy

- The cost of building and equipping 5 nm production lines is ~ 5.4 billion USD.
- It takes 12-24 months to create the fab shell & another 12-18 months to ramp up to full capacity. Even with govt subsidy & 55% capacity utilisation, it shall take a minimum of 10 years for such a fab to break even by which the tech may have completely changed. Hence, private capital is muted [3].

Poor Linkages

- Under-developed co-operation with equipment suppliers & commitment from fabless companies to base their designs especially in leading-edge nodes [35].

Semiconductor IC Manufacturing SWOT

- Strength
- Weakness
- Opportunity
- Threat

Potential in Trailing Nodes & Specialty Fabs	• A large volume of components in analog mixed-signal & radio frequency chips (RF) used in phones and wireless devices, Internet of Things (IoT) devices, automotive & medical equipment are made using >90 nm technology [36] [37]. • Less capital-intensive Gallium Nitride fabs (esp. for 5G applications) [38]. • Opportunity for established foundries to set up offshore fabrication units in India to maintain their older nodes at low cost [39].
Rising Geopolitical Conflicts	• China has a significant presence in manufacturing at trailing edge nodes and is scaling capacity even further. The threat of nationalisation of these units and the control exercised by China to regulate the supply of these chips have made the world nervous. It partially explains the rationale of the CHIPS Act (~50 billion USD fund) [40]. • A Quad partnership could help India to harness this opportunity & build linkages for raw material supply, EDA licenses & manufacturing equipment access [1].
High investments by other nations	• Global sales of semiconductor manufacturing equipment by original equipment manufacturers are forecast to soar 34% this year to 95.3 billion USD. • This is based on the substantial fiscal stimulus for fabs announced by the US, South Korea, Japan & EU. Considering this, India's incentives may not be enough [41].

Semiconductor IC Assembly, Testing & Packaging in India

The Outsourced Assembly & Testing (OSAT) exists as a separate segment because of its lean cost structures In India, though the costs of labour are low, OSATs haven't yet taken off due to the costs involved in importing wafers fabricated abroad. Government incentives to subsidise this cost are showing early results.

Semiconductor IC ATMP SWOT

- Strength
- Weakness
- Opportunity
- Threat

Low Cost Labour Availability

- The Outsourced Semiconductor Assembly & Testing (OSAT) model is a labour intensive, high volume & low margin business. India has sufficient labour availability (diploma & B.Tech in EE / Mechanical & Electronics) that can be employed as shop floor technicians or entry-level engineering staff [42].

Congenial Policy Regime

- In 2019 alone, 290 million mobile handsets worth 30 billion USD were produced in India. The 5X growth achieved in 5 years can be attributed to the Production Linked Incentive (PLI) scheme that makes assembling in India cost-competitive with China & Vietnam. Based on the interest expressed by OSAT/ODM & OEMs, additional handset manufacturing of nearly 10% of the global market by value and volume could move to India by 2023-24 [43].

Inadequate Backward Linkages

- Strong design ecosystem can be a strength for OSAT/EMS providers to give value added services (role of ODM) at a competitive cost [44].
- Most ATMP units are coupled with strong fab linkages. With the exception of trailing edge nodes & specialty fabs (Gallium Nitride) that may be established in India, it may not be practical to have a fab outside create a finished wafer, transport to India for ATMP and then re-export finished product abroad.

Semiconductor IC ATMP SWOT

Demand for Diversification

- The ATMP arena is dependent on a very few players (mostly in China & Taiwan)
- Amidst geopolitical tensions between US & China, fabless companies & integrated device manufacturers are looking to diversify their ATMP partners.
- Two fires at a package substrate plant in Taiwan in 2020 & 2021 exacerbated the global capacity shortage for ATMP services (already under stress to meet the surge in semiconductor demand in 2020) [5].

High Middle Class Consumption

- By 2027 India's population is set to overtake China's and the middle class will overtake that of the United States, Europe, and China. A large market for electronics, industrial automation & automotive is an incentive for ODMs /OEMS & OSATs to establish a base in India.
- Government policies incentivising the expansion of end-use verticals such as national fiber-optic networks, 5G communication, and electric vehicles can create an ecosystem for domestic chip assembly.

Strength

Weakness

Opportunity

Threat

Semiconductor IC ATMP SWOT

Competition with Vietnam

- Vietnam is fast emerging as the preferred choice in outsourced assembly operations for chip manufacturers (ex: Intel & Samsung).
- Can be attributed to the availability of low-cost semi-skilled labour, growing data centre & consumer electronics markets, and favourable tax incentives by the government.
- Also, Vietnam's proximity to China (an important source of raw materials) and participation in the Trans-Pacific Partnership treaty (no tariff on export to 12 nations) brings in substantial cost advantages [45].

Demand for R&D in Packaging

- In traditional die-level scaling, the idea is to pack ever more transistors on a system on chip (SoC) in decreasing wafer size. However, costs & manufacturing complexities are too high at this stage.
- Focus has shifted to R&D in system-level interconnection density [46] & advanced packaging (2.5D or 3D) for similar outcomes [47].
- R&D spends will gradually take over cheap labor availability as the comparative advantage. India may have a small window to capitalise on its labor strength.

Dumping by China

- China is currently the market leader in the OSAT space. It may be difficult for India to compete if Chinese products at highly competitive prices start flooding the market.

Strength

Weakness

Opportunity

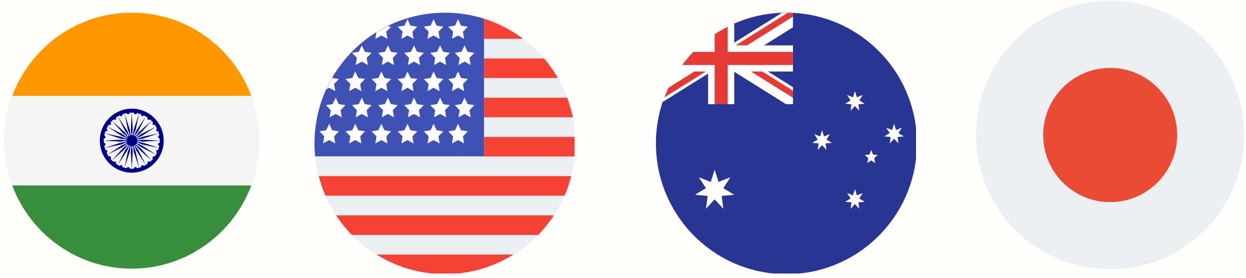
Threat

Recommendations

In the previous section, we analysed the SWOT of the entire semiconductor ecosystem in India. In this section, we list down a few policy recommendations for India based on a comparative advantage approach. We look at reinforcing the strength of the design ecosystem with special focus on high end talent pool & indigenous IP creation. For accelerating nascent sectors such as manufacturing & ATMP, "looking outward" and actively seeking global partnerships & trade linkages is a necessity.

Recommendations

1. Initiate a Quad Semiconductor Supply Chain Resilience Fund



The Quad countries (India, United States, Australia & Japan) have complementary capabilities (human capital, R&D and design strength, materials & chemicals respectively) in the semiconductor value chain. They could pool in resources to set up a Quad Supply Chain Resilience Fund that focuses on:

One, semiconductor manufacturing facilities across these countries. The focus has to move beyond leading-edge nodes (i.e. >28 nm) where significant market opportunity (ex: 5G, electric vehicles, AI) exists.

Two, new standard developments such as composite semiconductors and creating one centre for excellence in each Quad country in an area of its immediate interest. For example, Australia could host the CoE for new materials in electronics, Japan could host the CoE for silicon manufacturing equipment, while the US and India could host CoEs on specific fabless design architectures.

Three, facilitate strategic alliances between companies in the four quad states by reducing export controls, lowering investment screening mechanisms, and harmonising intellectual property cooperation mechanisms.

Since the Quad isn't completely self-sufficient, this partnership should remain open to establishing linkages with like-minded countries like the EU & East Asia as need be.

Recommendations

2. Strengthen Design IP Creation

India needs to invest in advancing research & development in semiconductor-related fields such as material sciences, computer science, engineering, and applied mathematics. to spur innovations. Government funds have to be earmarked to drive chip breakthroughs in strategic sectors such as defence, space & communication. To attract FDI in R&D, India will have to enhance the quality of the talent pool (research or practical experience), improve contract enforcement, revisit export controls & strengthen IP protection.

The Union government will have to facilitate FTAs & cross-licensing agreements without inducing any fear of being sued for patent infringement. Enabling a patent prosecution highway could prevent IP theft, accelerate patent prosecution, reduce scrutiny efforts & improve patent quality. Pooling private investment for handling EDA tool & IP acquisition costs may be useful in encouraging local design startups to file for patents. Liberalising higher education and promoting industry linkages should be evaluated for generating quality research output from academia.

Recommendations

3. Skilling Talent

While India has a sizeable number of STEM graduates, their skill levels will have to expand beyond the traditional strengths in design. Certain relevant areas include product conceptualisation, AI chip design on cloud architectures & network edge, analog & mixed-signal devices,, advanced manufacturing & packaging techniques., and general project management. There may be an opportunity to create for-profit centres of excellence in PPP mode on the lines of IMEC Belgium.

These CoEs could offer state-of-the-art infrastructure, fellowship to graduates, and corporate innovation accelerator programs. In areas of R&D, design & manufacturing, there is a demand for postgraduates and PhDs in relevant fields. India needs to design a talent program (with financial incentives & ease of relocation) to attract expatriates. In areas of ATMP, Skill India Mission will have to focus on addressing the skill gaps in system integration, testing & quality certification.

Conclusion

A detailed SWOT analysis of India's semiconductor value chain indicates that it is best poised to create a world class fabless ecosystem provided policies & incentives facilitating indigenous design IP creation are put in place. At a time when global semiconductor talent shortage is on the rise, India will have to ensure that its skilling policies are aligned with industry demands. In the absence of domestic self-sufficiency in raw materials, equipment, capital, and expertise required for manufacturing and ATMP, India will have to "look outward" and leverage its geo-political proximity to Quad & other groupings to make joint investments and faciliate trade flows. India needs to play to its strengths, act quick, and lay down clear policy priorities to communicate its focus on this meta-critical industry.

Appendix: Government Policies

NATIONAL POLICY OF ELECTRONICS (NPE), 2019

Target to achieve 400 billion USD of electronics manufacturing by 2025

MODIFIED SPECIAL INCENTIVE SCHEME (M-SIPS) [48]

- Subsidy to companies for capital expenditure - 20% in SEZ & 25% in other places. The upper cap of 1.35 billion USD applicable for 5 years
- Mandatory undertaking to keep operations on for 3 years after availing incentives
- Applicable for 44 categories across the value chain - component manufacturing + ATMP
- Uncertainty in policy regime & delay in processing incentives led to companies revoking their applications

PRODUCTION LINKED INCENTIVE (PLI) [32]

- Incentives of 4-6 % on incremental sales over 5 years to companies (set up or registered in India) producing electronic components in high volumes.
- Approx 540 billion USD outlay for manufacturing mobile & specified electronic components. High outlays for automotive components. Incentives for indigenous mobile phone manufacturers.
- Covers plant, equipment, R&D, and technology transfer costs.
- Launched in Aug 2020. Has attracted multiple applications.

MODIFIED ELECTRONIC MANUFACTURING CLUSTER (EMC 2.0) [32]

- Financial assistance for setting up of both EMC projects and Common Facility Centres (CFCs) across India
- Create plug & play facilities
- Promotes a cluster-based approach to strengthen supply chain responsiveness, consolidate suppliers, decrease time-to-market, lower logistics costs
- Outlay of 0.7 billion USD (3+5 years)

SCHEME FOR PROMOTION OF SPECIAL ELECTRONICS & SEMICONDUCTORS (SPECS) [32]

- 25% on capital expenditure for high value adding electronic products in downstream, i.e., electronic components, semiconductor/ display fabrication units, ATMP, specialized sub-assemblies & capital goods
- Applicable for both new & diversifying units
- Outlay of 0.7 billion USD (3+5 years)

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Acknowledgment:
We express our gratitude to Mihir Mahajan, Arun Mampazhy, Muthukrishnan Chinnasamy, and Shambhavi Naik for their insights and feedback.