Manufacturing the Digital Revolution: Building a Sustainable Supply Chain for ICT-Driven Development in India

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Abstract

As adoption of digital technology has accelerated in India, so too has demand for the minerals, hardware components and devices that collectively form the building blocks of the ICT ecosystem. Existing supply constraints are limiting India's ability to build out its digital infrastructure, pointing to an opportunity to expand a sustainable domestic supply chain for these materials. Assembly and fabrication of foreign components can provide easy wins for Indian manufacturing, urged on by high government incentives for Foreign Direct Investment (FDI) in semiconductor manufacturing. Chip fabrication remains an emergent industry within India, but Indian engineers have substantial expertise in designing chips which could be leveraged for domestic manufacturing. India also has substantial mineral resources for battery and semiconductor manufacturing which the nascent industry can take advantage of. Whether manufacturers choose to source raw materials from within India or from locations further afield, the Government of India (GOI) should coordinate with companies to build sustainable legal regimes around mineral extraction which minimize potential for corruption and maximize inclusive local benefits. This effort can go hand-in-hand with India's broader international development priorities, including international applications of Indian platforms for ICT-driven development in fields such as education and health.

Introduction

India's economy is in the process of experiencing an epochal transition, driven by a burgeoning digital sector. The country's IT industry is expected to grow by over 50% from today to 300-350 billion USD by 2026, with digital services constituting up to 200 billion USD of industry value. Emerging technologies such as AI and machine learning could generate up to 285 billion USD in economic value within India by 2030, according to a McKinsey analysis.[1] In addition to India's thriving digital services sector, the country also boasts one of the world's fastest growing markets for digital consumers. Over 750 million Indians are currently on the internet, a figure projected to reach 900 million by 2025 and over 1.5 billion by 2040. This would likely make India the single country with the highest number of internet users by this time.[2] Furthermore, the latest innovations in Information and Communications Technology (ICT) are currently being mainstreamed across all sectors of India's society. Closing the digital divide in India will yield tremendous improvements in basic development outcomes in areas such as nutrition, education, and health, as increased information transparency and speed of transmission contributes to more liquid markets and increased coordination within and between economic sectors. In sum, the rise of a digital India will revolutionize economic and development outcomes throughout the country – one main reason why the Government of India (GOI) has made its Digital India campaign one of the centerpieces of its current mandate. The strong emphasis on digitization in the 2022 Union Budget only underlines the importance of these trends.

Building India's new digital economy holds great promise, but it cannot take place absent a few key prerequisites. First, basic electrical and adequate digital infrastructure must be put into place, investments which GOI has been making under programs such as the *Saubhagya* scheme, which delivered an electrical connection covering every village in India and all households that submitted an application under the scheme, and *BharatNet*, a public broadband provider founded in 2012 with the intention of delivering 100 Mb/s broadband connectivity to all of the country's 250,000 gram panchayats. Beyond hard infrastructure, digital services must be established and the population must attain an adequate familiarity with digital products to ensure this infrastructure can be used by its beneficiaries to its full benefit. This process of closing the digital divide by making internet services more accessible to India's poor is a long one, and one which GOI has been undertaking through programs ranging from the *Aadhaar* national identification system to new online payment systems such as the Unified Payments Interface (UPI) introduced in 2016. Finally, a digital economy will also demand unprecedented manufacturing and distribution of digital devices for India's infrastructure, businesses, and consumers alike. India's smartphone market grew 23% YoY in the first quarter of 2021 alone, with the number of smartphone users more than doubling to 845 million from 395 million just in 2017, and the total number of users projected to reach 1.53 billion by 2040. As the internet goes fully mobile and digitization pervades the Indian economy, India's demand for smart devices and Internet-of-Things (IoT) devices will similarly skyrocket.

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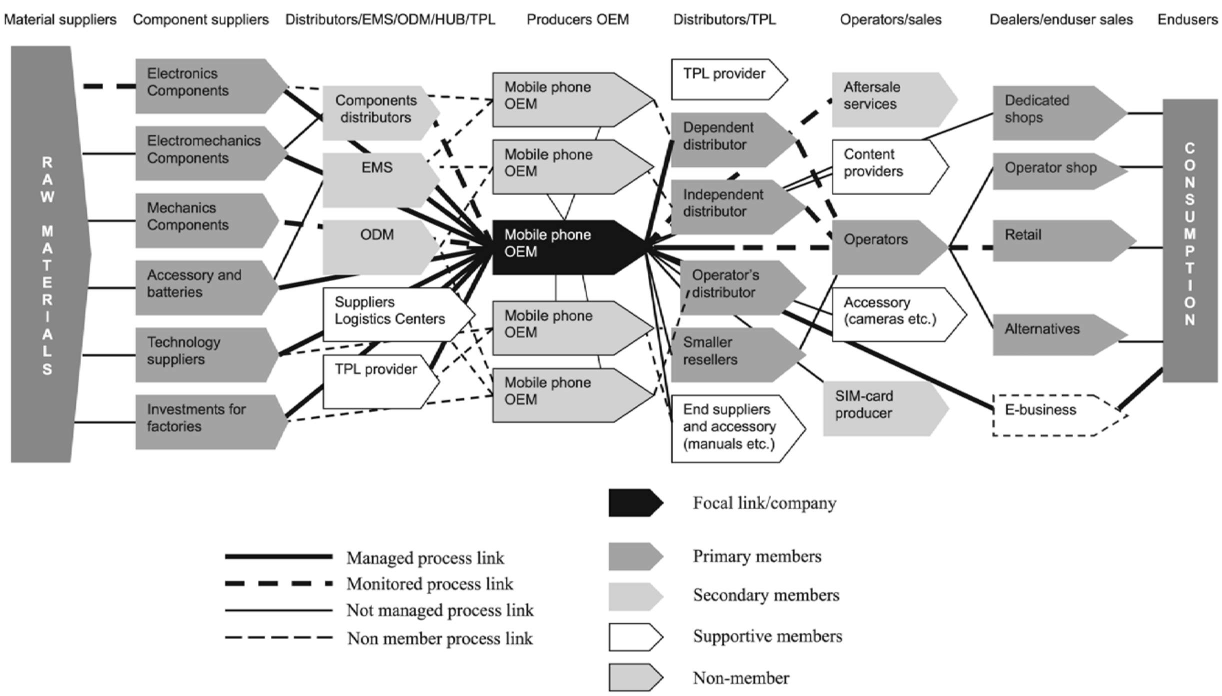
[1] https://www.vaneck.com/us/en/blogs/emerging-markets-equity/the-worlds-digital-transformation-is-made-in-india

[2] https://economictimes.indiatimes.com/tech/technology/india-to-have-900-million-active-internet-users-by-2025-says-report/articleshow/83200683.cms

Few studies have been produced on the viability of India's digital manufacturing supply chain to stay abreast of these near-future trends. But while India could certainly strive to digitize its economy while continuing to import the vast majority of the hardware necessary for such an endeavor, onshoring its digital manufacturing supply chain would make these efforts more successful, stable, and robust to events such as geopolitical disruptions and commodity price fluctuations. Stronger domestic electronics brands would also support national security goals and help India meet the privacy and data protection standards stipulated under the 2019 Personal Data Protection Bill. These benefits point to why GOI has implemented policies in recent years to provide official support to India's domestic electronics manufacturers. Not only does domestic digital manufacturing align with the government's broader economic goals to boost the manufacturing sector and align its production to the needs of the future global economy, it backstops India's own shift towards a digital economy. By taking charge of its own electronics manufacturing supply chain, India also has the chance to pioneer the implementation of best practices in sustainable development across numerous economic sectors. In short, India has the power to develop its electronics manufacturing industry into a global engine for sustainable development, centered on Indian technology and Indian know-how. This analysis will examine this path by describing the current state of digital technology sourcing within India, exploring how India's digital manufacturers are seeking to capture more value from the production process, and investigating how raw materials can be sourced in an ethical and sustainable manner which synergizes with India's other international initiatives, using the smartphone industry as an example.

India's ICT Supply Chain



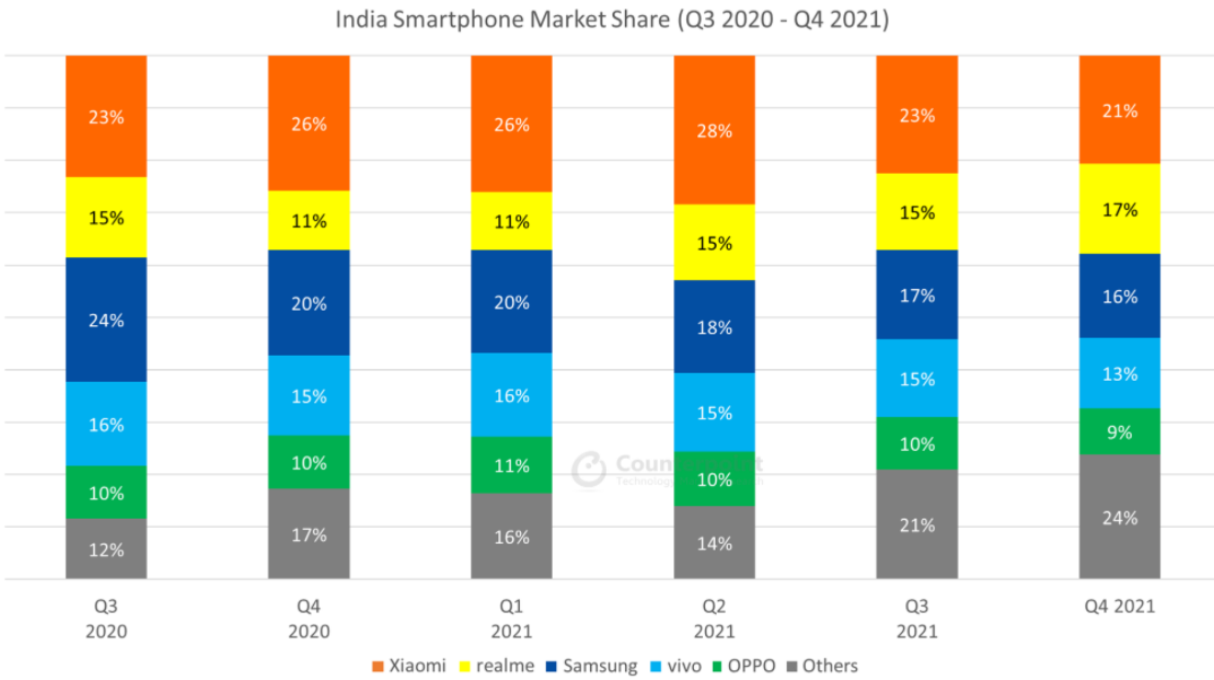
The smartphone supply chain, like other ICT devices, is a complex network of arrangements between raw material suppliers, component manufacturers, assemblers, distributors, and retailers. Source: Hess, Martin.

An Overview of Global Electronics Manufacturing

The manufacture of smartphones, like other digital devices, can be broken down into several discrete stages of production. Starting from the mining of ores such as coltan, bauxite, graphite, and hematite, key materials are extracted, refined, and delivered to the manufacturers of basic components such as screens, chips, casings, and batteries. Manufacturers of these components produce them according either to licensed external designs or according to their own designs, depending on the resources of their Research and Development (R&D) departments, required specifications, and market demands. Finally, these components are assembled to create devices which are then ready to be sold to consumers. These intermediate stages of production can be sourced from different places, but each one is likely to be completed in full in one place before the product is sent to its next destination along the supply chain. This means that industrial clusters which combine several functions along the supply chain accumulate an inherent advantage for every stage of the manufacturing process. These advantages are only heightened by the integration of ICT-driven management in manufacturing, which improves coordination between buyers and suppliers.

Companies have traditionally performed several of these roles along the supply chain, leading to the development over time of a terminology describing the various roles they play. Original Equipment Manufacturers (OEMs) are producers of original components, whose products serve as intermediate goods for manufacturers of other products. The producer of a final product using OEM components is referred to as a VAR, or value-added reseller. OEMs sell on a business-to-business model as “contract manufacturers” who produce components strictly according to a buyer’s specifications, while VARs sell their products to consumers. OEMs often use electronic parts manufactured by Contract Electronics Manufacturers (CEMs) for the production of more advanced electronic components such as circuit boards and cable assemblies, due to the high degree of specialized expertise required to manufacture these goods. In contrast with companies operating according to these contract-based manufacturing agreements, Original Design Manufacturers (ODMs) design and sell their own products, either under their own names or as “white label” products which can be rebranded by buyers. Because this arrangement implies a lack of customization, ODMs typically manufacture more basic products which can be marketed to consumers such as cases and chargers. ODMs also fill the niche of design shops for manufacturers requiring specific components and wishing to avoid Non-Recurring-Engineering (NRE) costs. Finally, Electronics Manufacturing Services (EMS) are manufacturers which design, manufacture, and sell electronic components from beginning to end, making sales both to VARs and consumers. Recently, EMS companies such as Taiwan’s Foxconn have begun expanding their R&D arms, and ODMs have expanded their manufacturing capabilities, resulting in a hybrid model between the two known as a DMS (Design Manufacturing Services) provider. Electronics manufacturers, therefore, can play a host of roles along the supply chain according to the needs of the businesses and consumers in their surrounding market.

India’s Foreign Manufacturers



India's smartphone market has been almost entirely dominated by foreign brands for years, in particular Chinese manufacturers marketing brands specifically for the Indian market. Source: Counterpoint Research

India's smartphone market is almost entirely dominated by imported foreign brands which focus their high-value design and manufacturing activities abroad. Of the top five smartphone brands, only one, Samsung, is not Chinese, and Vivo and OPPO are the entry-level and mid-level brands produced by the Chinese conglomerate BBK Electronics. Of the Chinese companies, only Xiaomi has experienced a level of global success approaching that of Samsung. However, the combination of reliability and affordability afforded by these Chinese manufacturers has displaced other brands, resulting in a dominant market position and high brand loyalty. Xiaomi, like other Chinese brands, first entered the Indian market in 2014 through an online-only model, allowing it to outprice Indian competitors. From 2017 onwards, though, the company rapidly expanded its brick-and-mortar retail network to 15,000 stores in 2021, and a planned 30,000 stores by March 2022. From 68% of domestic sales in 2015, Indian brands such as Micromax, Lava, Karbonn and Intex have been crowded out by these Chinese brands to constitute a mere 1% of domestic smartphone sales today, although Indian brands maintain a toehold in the feature phone market. Experts point to poor quality control, limited R&D, domestic failures to punctually develop 4G-capable devices, and umbrella branding strategies by competitors as the root causes of Indian consumers' shifting preferences.[3] Meanwhile, Apple's iPhone registers a mere 4.4% market share in the Indian market, thanks to its noncompetitive price, although it occupies 44% of the country's premium smartphone market.

[3] https://www.business-standard.com/podcast/current-affairs/how-did-chinese-smartphones-wipe-out-indian-brands-122011900113_1.html

Just because the vast majority of Indian smartphones are sold under foreign branding, however, does not mean they are imported in their entirety from abroad. In fact, 95% of phones sold in India are, at least in part, manufactured within India, and the country's 268 mobile phone and mobile accessory manufacturers employed 670,000 people as early as 2018. OPPO's "superfactory" in Noida sprawls across 110 acres, employs 10,000, and is capable of assembling over six million phones a month. Noida is also home to the largest Samsung plant in the world, producing as many as 120 million units per year. The opening of the 35-acre plant nearly tripled Samsung's capacity within India on its own, employing 70,000 workers. Originally, Samsung had used Noida solely for assembly of outside components, but in June 2021, it shifted its main smartphone display manufacturing unit to Noida from China, citing a better industrial environment and more industry-friendly policies. If display manufacturing in Noida is successful, it may pave the way for other foreign companies to start partnering with Indian manufacturers to build increasingly high-value components, rather than simply the low value-added work of assembling them into finished products. Realme, for instance, now boasts that "more than 60% of components are manufactured in India, and 100% of phones and televisions sold in India are assembled in India,"[4] and Vivo aimed to increase its localization level from 15% to 40% from 2020-21 in line with the GOI "Make in India" initiative.[5]

Foreign brands which manufacture devices within India's borders do, in a limited capacity, involve Indians in their R&D and design work as well. For instance, OPPO hosts a 400 person R&D unit in Hyderabad which innovates on both the hardware and software ends. This unit has contributed to developing upwards of 200 patents for trademarks such as the motorized pop-up camera, hybrid lossless zoom, and AI Night mode photography. OnePlus, BBK's brand for the premium market, also recently committed to expanding its R&D capabilities within India, and three of Samsung's 32 global R&D centers are located in India.[6] Samsung pledged to hire 1000 engineers for these centers, with 300 spots reserved for graduates from the prestigious IIT system. However, the nature of design processes for multinational corporations means that Indians working at these satellite facilities can likely only contribute to development of peripheral systems, and that opportunities for growth of the design and R&D sector are likely to be limited while these international companies dominate the market. For Indian manufacturers working with these companies, the nature of their contract work means they would likely operate on an OEM basis. This may provide opportunities for skill and knowledge transfer, but it will not offer opportunities to move into higher-value segments of the supply chain because it will not involve original design opportunities. Finally, excessive reliance on foreign brands in electronics manufacturing leaves India's electronics supply chains vulnerable to changes in corporate strategy, unacceptably so for a country planning a massive push into a digital economy. For instance, after South Korea's LG announced a 140M USD investment into India in 2015, it pivoted away from smartphones in 2018 in the face of poor sales and stiff competition. This has

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[4] https://asia.nikkei.com/Business/China-tech/China-s-Realme-to-expand-India-production-despite-COVID-surge#:~:text=All%20of%20the%20smartphones%20and,in%20India%2C%22%20Sheth%20said.&text=Realme%20ranked%20second%20in%20wireless%20headphones%20in%20India.

[5] https://economictimes.indiatimes.com/industry/cons-products/electronics/vivo-india-to-raise-localisation-level-to-40-by-2021/articleshow/79082382.cms?from=mdr

[6] https://www.eetindia.co.in/19012801-will-india-emerge-as-a-mobile-rd-hub/

left the company's India investment stagnant, relegating its Bangalore-based R&D unit to niche applications such as digital video broadcast and biometrics software.

Foreign Investment Policies

S.No.	Description	From	To
1.	Inputs, parts or sub-parts for manufacture of specified parts of mobile phones, including: (1) Printed Circuit Board Assembly (PCBA) (2) Camera module (3) Connectors [To apply with effect from 01.04.2021]	 0 0 0	 2.5% 2.5% 2.5%
2.	Printed Circuit Board Assembly [PCBA] and Moulded Plastic, for manufacture of charger or adapter	10%	15%
3.	Inputs and parts [other than PCBA and moulded plastic] of mobile charger	Nil	10%
4.	Inputs, Parts and Sub-parts [other than PCBA and Li-ion Cell] for manufacture of Lithium-ion battery and battery pack [w.e.f. 01.04.2021]	0	2.5%
5.	Compressor of Refrigerator/Air Conditioner	12.5%	15%
6.	Specified insulated wires and cables	7.5%	10%
7.	Specific parts of transformer such as Bobbins, brackets, wires, etc.	Nil	Applicable Rate
8.	Inputs and parts of LED lights or fixtures including LED Lamps	5%	10%
9.	Solar Inverters	5%	20%
10.	Solar lanterns or solar lamps	5%	15%

Import duties on certain mobile components were increased in April 2021 to encourage domestic manufacture of these parts, in coordination with a 27B USD five-year Production Linked Incentive (PLI) scheme to encourage large-scale electronics manufacturing. Source: Ministry of Electronics and Information Technology

In recent years, GOI has implemented a number of policies to encourage increased Foreign Direct Investment (FDI) in India's USD smartphone industry. These have sometimes taken the form of the stick: following an increase in import duties on certain mobile parts by amounts ranging from 2.5-15%, Xiaomi was recently ordered to pay 88M USD in back import taxes for components which had not been manufactured within India's borders. [7] These policies have also taken the form of the carrot: the recent expansion of smartphone manufacturing within India was encouraged by a total of 6.65B USD in incentives from GOI to companies which increase their production of smartphones within the country. These incentives are projected to directly create some 200,000 jobs and up to 600,000 indirect employment opportunities, in comparison with the 2 million employed in India's electronics manufacturing industry at the outset of the scheme.[8] [9]

[7] https://www.cnbc.com/2022/01/06/india-asks-xiaomi-to-pay-nearly-88-million-in-import-taxes.html
[8] https://www.cnn.com/2020/10/07/tech/india-smartphone-apple-intl-hnk/index.html
[9] https://techcrunch.com/2020/10/06/india-approves-apple-partners-and-samsung-for-143-billion-smartphone-manufacturing-plan/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAADrvr4nxED

India’s vast and expanding electronics manufacturing capacity, and its high levels of design talent, demonstrate that a full supply chain centered around Indian brands should be feasible. Strengthening the market power of Indian brands in the domestic manufacturing space would be the most straightforward way to ensure close coordination between the country’s corporate landscape and GOI’s industrial policy goals. Fortunately, in recent years, Indian brands have begun making a comeback, and corporations envision the possibility of substantial user growth in the near future. Lava announced India’s first domestic 5G phone, the Agni, in November 2021, at a 20,000 INR (264 USD) price point targeted comfortably at midmarket users and featuring specifications competitive with popular foreign offerings such as the Xiaomi Redmi Note 10T and the OnePlus Nord CE. Reliance Jio made waves last year when it unveiled the JioPhone Next, a phone made “by Indians, for Indians” with the explicit aim of closing the country’s digital divide. The product of an engineering partnership with Google, the JioPhone Next comes in at a miniscule 6400 INR (85 USD), outflanking most of its competitors on price while delivering what is said to be the best performance of any phone available under 10,000 INR (132 USD).[10] Uniquely in the global smartphone market, the JioPhone Next’s operating system Pragati OS will be capable of text and voice translation between ten regional Indian languages, meeting a need for its target niche met by no other company.

While other Indian phones face the uphill battle of winning over customers loyal to other brands, Reliance intends to circumvent the dominance of foreign manufacturers in the current Indian smartphone space by marketing to the hundreds of millions of Indians who still use feature phones – a large share of which are Reliance models. If the brand loyalty of feature phone users carries over, if Reliance can capitalize on existing subscribers to its telecom network through its broad retail network, or if Reliance continues to maintain sole possession of what has become a radically redefined budget smartphone market optimized for the needs of Indian consumers, the company could be in position to emerge as India’s dominant smartphone brand, opening up opportunities for Indians across the breadth of the entire electronics manufacturing supply chain and even potentially providing a pathway into the export market. Even if this attempt does not successfully break into the domestic consumer market, it will still help provide a manufacturing and skill base for India’s economic goals. Brand loyalty is less of a factor outside of the realm of consumer technology, meaning these domestic supply chains, once complete, could easily serve to produce other electronic hardware through public contracts instead of smartphones.

Component Manufacturing and Design

From 2016-20, the GOI implemented a “Phased Manufacturing Program” (PMP), which was intended to shift Indian electronics manufacturing into the production of higher value components through the progressive imposition of customs duties of between 15-20% over time. Starting by introducing duties on low-value accessories such as chargers, headphones, and

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[10] https://www.news18.com/news/tech/why-jiophone-next-developed-by-reliance-google-may-be-the-best-4g-phone-under-rs-10000-2-4400414.html

batteries in 2016-17, when the electronics manufacturing sector was still emerging, the PMP moved on to introduce customs duties on electromechanical components such as microphones, cables, and key pads in 2017-18, circuit boards in 2018-19, and touch displays in 2019-20. The PMP contributed to an expansion in foreign investment into Indian contract manufacturers, which increased contract production from 13.4B USD in 2016-7 to 31.7B USD in 2019-20. But value addition has remained low, despite the goals of the tariff program. Annual Survey of Industries (ASI) data from 2018-19 indicates that for most firms, value added in Indian manufacturing does not exceed 10%, and that 85% of inputs for surveyed firms were imported. On a whole, India's imports of mobile phone components exceeded its exports by 25 times, in contrast with competitor manufacturing hubs such as China, Vietnam, South Korea, and Singapore, all of which exported more parts than they imported. Such an outcome indicates that despite the growth in contract manufacturing within India in recent years, these domestic producers have not been able to invest in facilities that would contribute to value addition and moving higher on the supply chain. Furthermore, Taiwan has contested the PMP at the WTO, charging that the raise in tariffs was not in compliance with GATT. The WTO judgement on the case is due in Q2 2022.[11] Developing countries receive special provisions under the WTO Agreements, but should the panel judge the case against India, investments made within the context of the PMP could become unviable.

The Production Linked Incentive (PLI) scheme, introduced in 2020 at the conclusion of the PMP, took a different tack in order to address some of the earlier program's deficiencies. The PLI offered a 4-6% incentive on production value for applicants which met benchmarks for domestic investment and production. Not a single Chinese manufacturer applied to the scheme, but a total of 16 domestic and international firms did apply successfully, although 15 of these have announced delays in meeting targets under the scheme in the face of chip shortages. While foreign firms only receive incentives for sales of mobile phones priced over 15,000 INR, domestic firms face no such incentive floor.[12] One domestic PLI applicant, UTL Neolync, is actually a joint venture between India's UTL and an Israeli firm with deep investment from Reliance, existing mainly as a platform for Reliance to manufacture the JioPhone Next. The India Cellular and Electronics Association (ICEA), an apex body for promoting electronics manufacturing within India, has identified further opportunities within the 27B USD PLI scheme for expanding India's smartphone design, R&D and application ecosystem, envisioning a path to making India a global export leader of smartphones by 2025.[13] If benchmarks are ultimately reached, domestic value addition is projected to increase to 35-40% for mobile phones and 45-50% for electronic components by 2025, alongside an expansion in mobile phone production capacity by some 600 million units per year. These additional units are likely to be targeted towards the international market, and low-price exports to poorer countries are expected to be the most competitive.[14] If domestic firms do manage to achieve a substantial international market

[11] https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds588_e.htm
[12] https://www.zenger.news/2020/10/28/india-aims-to-become-global-superpower-in-smartphone-manufacturing/
[13] https://economictimes.indiatimes.com/industry/cons-products/electronics/icea-plans-bigger-push-for-smartphone-design-rd-in-india/articleshow/80215468.cms
[14] https://www.thehindubusinessline.com/info-tech/centre-clears-16-proposals-entailing-11k-cr-investment-for-making-mobile-phones/article32784470.ece

share, they will do so in defiance of their recent performance; Lava reported just 43M USD in exports in 2018, while Optiemus reported just 11M USD in exports that same year.[15] Whether PLI will be able to revolutionize these firms' international competitiveness remains an open question.

In Reliance's case, the decision to shift its smartphone supply chain to India was the fruit of bitter experience. The Jio LYF, Reliance's first smartphone, was manufactured through partnership contracts with Chinese companies such as ZTE, Wingtech, and Tinno Mobile. But poor quality control from these suppliers and production delays would plague the company, delaying its launch by over a year. The LYF finally would launch, but the delays cost the company a valuable period of market consolidation which could not be regained. By 2018, LYF's market share had plunged from 7% to under 2%, as Chinese majors began flooding the Indian smartphone market. This time around, Reliance's decision not just to partner with domestic suppliers under the PLI scheme, but to take control of its manufacturers through an investment, is a clear gesture at securing the strategic relationships which sabotaged its initial attempt to distribute a smartphone that would define the Indian market. Reliance's experience echoes the *Atmanirbhar Bharat* vision of an Indian digital economy that consolidates critical manufacturing under domestic control, rather than relying on imports for critical hardware. The strategy comes at a substantial cost for now – Ernst and Young estimates that the effective cost of manufacturing mobile phones within India is 16% higher than within China and 4% higher than within Vietnam – but with the potential of future payoffs following investments in domestic efficiency.

Reliance is manufacturing the JioPhone Next at the Karbonn plant in Tirupati, Andhra Pradesh, and through a contract manufacturer in Sriperumbudur, Tamil Nadu, a growing electronics manufacturing hub home to plants managed by major players such as Foxconn and Flextronics. But on the whole, Reliance's domestic manufacturing strategy is likely to run into component shortages and supply chain constraints, with chip supplies a major bottleneck. The company's stated goal of producing 50 million smartphones within the first six months of release, compared to Samsung's annual capacity of 60 million and OPPO's annual capacity of 50 million, runs counter to the stark reality of India's underdeveloped component manufacturing supply chain. While imports could temporarily fill this gap, global semiconductor prices have recently skyrocketed due to demand in the cryptocurrency space and US sanctions of Huawei, making this approach less feasible.

Reliance, then, will need to target investments into other domestic contract manufacturers to increase its chipset availability. Fortunately, new investments made under PLI and its sister program, the six-year, 10B USD India Semiconductor Mission (ISM), are beginning to meet this demand. On February 14, 2022, Foxconn announced a 119M USD joint venture with the Indian natural resources company Vedanta to produce semiconductors in India, with Vedanta as majority stakeholder. The new agreement is one of the first to emerge since GOI began accepting applications on January 1 this year to the ISM, which offers support for up to 50% of project cost

[15] https://www.thehindu.com/opinion/lead/phased-manufacturing-policy-that-is-hardly-smart/article32856521.ece

for new electronics manufacturing capital investments, depending on the type of plant and the degree of potential value addition, while also supporting modernization of the Semiconductor Laboratory (SCL) in Mohali, India's chief public semiconductor research center.[16] The government expects at least a dozen semiconductor manufacturers to open operations in India within the next 2-3 years, and has requested companies to provide road maps for moving from basic production techniques like fabrication of mature 28nm to 45nm parts to more advanced, higher value-added operations.[17] Encouraging PLI partner firms to colocate their supply chains within India in this manner could be a prerequisite not just to developing Indian talent and heightening value retention, but also to ensuring that Indian electronics manufacturing becomes viable in the export market in the way it needs to be.

As long as PLI and ISM investments are matched by investments towards a sustainable supply ecosystem, these moves should accelerate value creation in the electronics manufacturing space by increasing the production of technology-intensive components such as display assemblies and touch panels. In particular, these planned investments will boost the development of India's nascent Printed Circuit Board (PCB) manufacturing and design industry. At the moment, India is actually one of the world's largest chip designers, with over 20,000 engineers in the country designing an estimated 2000 chips per year.[18] But talent shortages along the rest of the semiconductor supply chain prevent manufacturing from keeping up with demand, with domestic production only meeting 35% of domestic demand.[19] Theoretically, India's low-cost technical workforce gives it an advantage in semiconductor design and manufacturing, should it find an appropriate strategy for skilling workers in the appropriate areas. Indeed, the global chip shortage offers India a golden opportunity to rebrand itself as a manufacturing and design services provider, a goal GOI has prioritized by investing an estimated 30.6B USD into developing India's electronics manufacturing capacity to date under the aforementioned policies.[20] So how should India approach the challenge of expanding its hold on the semiconductor manufacturing industry?

Computer chips, or Integrated Circuits (ICs), are themselves a highly complex product whose manufacture operates according to its own supply chain, First, manufacturers design new chips, a stage which captures 30% of the sector's overall revenue. Over half of market share in chip design is controlled by American companies like Qualcomm, Nvidia, and AMD, but India plans to invest in the development of high-tech clusters which will support 85,000 researchers with the goal of setting up 20 semiconductor design companies of its own. The next step, manufacture of silicon wafers, involves slicing purified silicon "ingots" into sheets which are typically under a millimeter in thickness. This stage captures only 3-5% of total revenue, taking place largely in Japan, and entry is gated by access to expensive patented technology. The third stage, chip

[16] https://www.businesstoday.in/latest/economy/story/govts-roadmap-to-make-india-hub-of-semiconductor-manufacturing-315701-2021-12-15
[17] https://www.bloomberg.com/news/articles/2021-12-22/india-sees-chip-makers-starting-local-manufacturing-in-2-3-years
[18] https://indiaai.gov.in/article/building-designing-semiconductors-where-does-india-stand
[19] https://www.electronicsb2b.com/eb-specials/industry-report/where-is-the-indian-pcb-industry-headed/
[20] https://www.business-standard.com/article/economy-policy/semiconductor-mission-launched-by-it-minister-ashwini-vaishnaw-121123100044_1.html

fabrication, requires access to advanced devices which use specialized equipment, chemicals, and gases to convert silicon wafers into chip prototypes. Purchasing and maintaining these capital goods is itself a major part of the supply chain, representing 15% of total industry revenues. Only the Dutch company ASML manufacturers the lithography devices used in the current standard of fabrication techniques, extreme ultraviolet lithography (EUV), and only ASML and Taiwan's TSMC operate these machines so far. However, they allow for the fabrication of 5 nm chips, which will soon make chips produced through different techniques obsolete. Operating these chip fabrication units, or fabs, captures a further 40% of market revenue. This is either done through vertically integrated manufacturers or by open-market CEM "foundries" such as TSMC. India plans to establish two semiconductor fabs and two display fabs, modernizing a third fab through a joint venture with a fab partner, to enter this space. Alternatively, fabless manufacturing, in which producers design and package chips while outsourcing their fabrication to a dedicated foundry, could allow India to achieve strategic autonomy while skipping this highly capital-intensive step, and the ISM is offering Design-Linked Incentives (DLI) of up to 50% through ISM as well. Finally, Assembly, Testing, Marketing, and Packaging (ATMP) makes up the final 10% of industry revenue. Taiwan and China dominate this segment at the moment with a 50% combined market share, but India plans to become a substantial presence within the space by founding 15 new ATMP units within the next few years. This stage, the least capital-intensive, is where India can start skilling its technical workforce without first making investments on the order of the 15-20B USD required for a cutting-edge fab.[21]

If India hopes to make substantial inroads into the remainder of the IC manufacturing supply chain, particularly the design and fabrication operations it has already made investments into, it will need to seek out opportunities for skill and technology transfer. India has already announced a chip-to-startup (C2S) incubator program which will train 85,000 engineers in techniques for semiconductor manufacturing, but even more opportunity can be found by setting up joint ventures between Indian companies and multinational chip manufacturers. Because so many countries seek to move into the IC business, these companies benefit from a competitive seller's market. On an annual basis, Samsung attracts 8B USD, Intel attracts 7B USD, TSMC attracts 4B USD, Qualcomm attracts 3.8B USD, and Micron attracts a further 3.8B USD in direct subsidies and tax benefits from countries seeking to bring their operations within their borders.[22] However, the high returns to gaining experience in chip design and manufacturing means that India's own subsidy-forward approach, despite competition, is likely one of the best means to maximize opportunities for technology transfer. India does not have to limit this learning to within its own borders; an intergovernmental partnership to send Indian engineers to work as fellows within these firms would be largely as effective, without having to wait for the substantial capital investments of new plants within India to be completed. Indian engineers already hold key positions on R&D teams at cutting-edge international IC design firms, a skill pipeline which policy should take greater advantage of. The burgeoning US-China rivalry in the technology space has led many countries to seek out alternative locations for semiconductor manufacturing,

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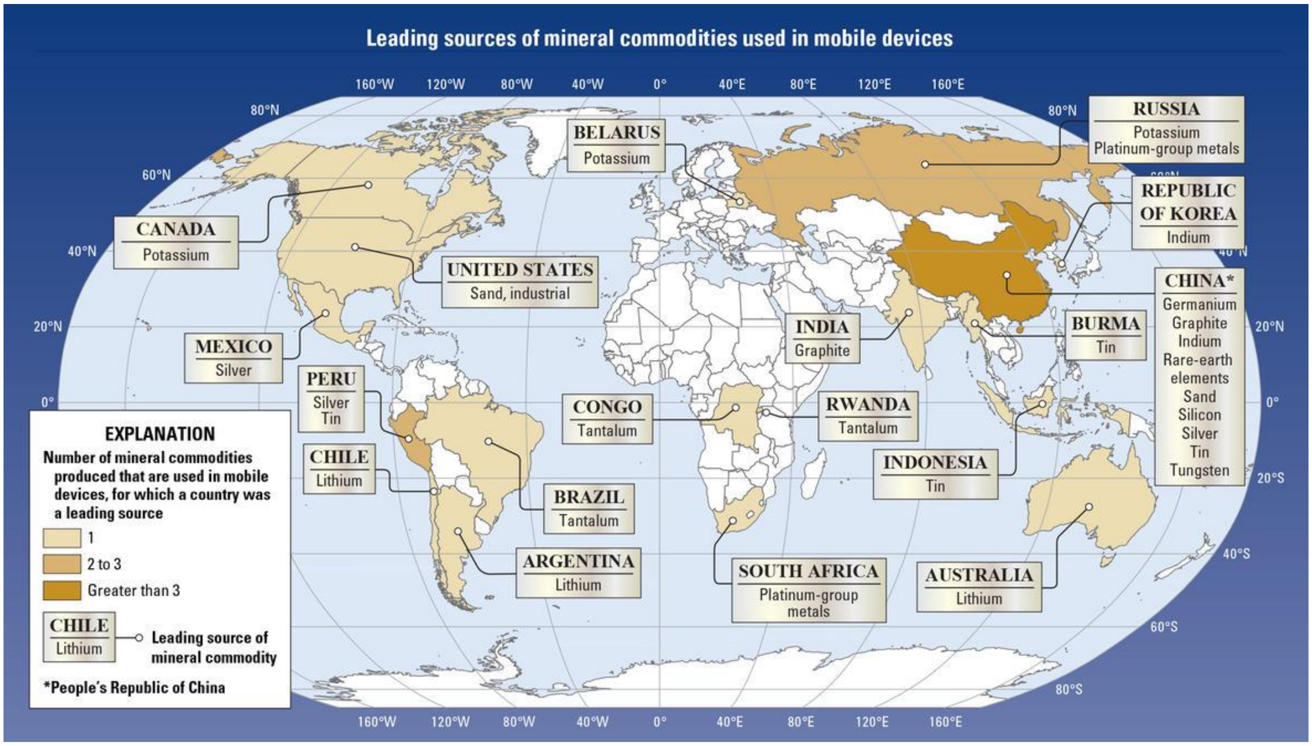
[21] https://www.livemint.com/technology/tech-news/indias-journey-in-chip-making-may-start-with-atmps-11623259001571.html

[22] https://www.thehindubusinessline.com/opinion/india-can-be-a-winner-in-semiconductors/article38057577.ece

with India near the top of the list. India can seize this opportunity to become a new semiconductor manufacturing hub if it acts now to skill its technical workers in the most critical, value-intensive segments of the IC supply chain as quickly as possible. The ISM, which incidentally is accepting applications for top officials such as a CEO, CTO, and CFO through February 20, would be the ideal body to coordinate these tasks.[23]

Resource Operations



Smartphones require a vast array of raw materials, sourced from across the world. India is a leading producer of some of these minerals, and Indian companies run mining and refining operations in other crucial countries, but a secure, robust, and sustainable electronics manufacturing supply chain will require solidifying a hold over these critical materials in a way aligned with foreign policy goals and principles of sustainable development. Source: USGS.

Electronics, especially smartphones, are the end products of some of the most diverse and wide-reaching supply chains in the world. Their manufacture requires the input of dozens of different minerals and other raw materials, many of which are difficult to source and serve highly specialized purposes. To give a brief overview of some of the most used materials that go into a smartphone:

- Copper is the most important conductor used in electrical wiring, and is the most used metal in mobile phone components. Growing global demand for electronics means that copper supplies will run short soon without an increase in supply.

[23] https://economictimes.indiatimes.com/news/economy/policy/meity-to-hire-ceo-cto-cfo-for-india-semiconductor-mission-official/articleshow/89384462.cms

- Tellurium, extracted as a byproduct from copper and lead ore, can be alloyed with other metals to increase their hardness and resist corrosion. It is also a key ingredient in processes used for tinting glass and manufacturing solar panels.
- Lithium forms the backbone of modern rechargeable batteries, and is most often found in salt brines, especially endorheic lakes in desert regions of countries such as Australia, Chile, Argentina and China. Like copper, lithium demand will expand as demand for portable electronics grows, leading to potential shortages.
- Cobalt is used to coat wires within ICs to prevent them from eroding over time. A byproduct of nickel-copper mining, the majority of the world's cobalt is sourced from the Democratic Republic of Congo (DRC).
- Manganese, 80% of which is mined in South Africa, will likely be central to the next generation of rechargeable mobile batteries. The element also makes electronics less prone to degradation and failure.
- Graphite is used for heat dispersion in circuits, batteries, and displays, reducing the potential for overheating. New graphite processing techniques could also viably produce an alternative form of carbon, graphene, as an alternative to the rare-earth element indium for building touch screens. India is one of the world's largest producers of graphite, extracting 34,000 tons in 2020.
- Tantalum and niobium, two elements extracted from columbite-tantalite ore (coltan), are known for their high levels of conductivity and resistance to corrosion, and are used jointly in capacitors, superconductors, and resistors. Coltan is a so-called "conflict mineral," often extracted under hazardous and lawless conditions in countries lacking strong institutions and experiencing violent conflict.

Beyond these major elements, modern electronics of all types are also dependent on Technology-Critical Elements (TCEs), rare elements designated for their unique applications in emerging technologies and their accelerating usage in recent years. These include six of the platinum-group elements (iridium, osmium, palladium, platinum, ruthenium, and rhodium), "noble metals" known for their stable electrical properties; the 17 rare-earth elements (cerium, erbium, gadolinium, lanthanum, neodymium, promethium, scandium, thulium, yttrium, dysprosium, europium, holmium, lutetium, praseodymium, samarium, terbium, and ytterbium), whose applications range from high-performance magnets to fiber optics and LCD screens; and twelve additional elements (antimony, beryllium, cesium, gallium, germanium, tungsten, and the aforementioned cobalt, lithium, tellurium, indium, tantalum, and niobium) mostly used in capacitors, alloys, and conductive coatings. Of these materials, the rare-earth elements are the scarcest and most strategic resources for electronics manufacturing. Rare-earth elements are not particularly rare on earth, but they are challenging to economically extract because they are evenly dispersed and are rarely found concentrated within minerals. Mining rare-earth elements therefore often requires a bulk approach which is highly damaging to the surrounding environment unless extra expense is directed towards mitigating this harm. Where rare-earth ores do exist, they are often mixed with substances which contaminate the water and soil and, in some cases, are even radioactive.

Until the 1980s, the United States was the world's dominant rare-earths producer, led by California's Mountain Pass mine. But rare-earth production then began ramping up rapidly in China, spurred on by the discovery of deposits in Inner Mongolia, the realization of their strategic value, and their formal branding as a strategic commodity. In 1992, Chairman Deng Xiaoping remarked that "the Middle East has oil; China has rare-earths," pointing to the esteem Chinese leaders held for this new resource. Rare-earth production increased by an average of 40% annually in China between 1978 and 1989, powered both by large state operations and mass informal and illegal mining operations. [24] Skyrocketing Chinese exports of rare-earths, subsidized by the state, eventually tanked their prices on the international market,[25] driving what was once the world's largest producer in Mountain Pass first out of the rare-earths business in 1998 and then to close entirely in 2002. Although the mine reopened in 2012, it has since struggled with bankruptcy and repeated closures, reflecting the troubles other legacy suppliers have faced following China's rise in the industry. China's control of the rare-earths market peaked as high as 97.7% in 2010, despite only holding an estimated 30% of the world's reserves. The country has demonstrated its willingness to use its near-monopoly over the industry as leverage in the past. After a dispute at sea, China quietly shut down rare-earths exports to Japan, causing prices to increase there by roughly 1000%. More recently, China reportedly prepared to restrict exports to the US during the 2019 trade dispute in defiance of WTO regulations.[26] Alarmed by this sudden vulnerability, various countries have since made moves into the rare-earths industry to serve as alternative sources for global supply. In 2020, China's share of global rare-earth metals production had dropped to 58%, compared to 16% for the United States, 12% for Burma, 7% for Australia, 3.3% for Madagascar, 1.2% for India and 1.1% for Russia. However, much of this drop was due to China's shift towards less polluting mining techniques, which new entrants to the market would hopefully replicate. Rebuilding supply chains around new suppliers remains costly and time-consuming, and refining capacity remains concentrated in China.

Eyeing China's success in rare-earths, the India Electronics and Semiconductor Association (IESA) recently published a report suggesting that India should aim to supply raw materials to the global electronics manufacturing sector. The jury remains out on whether such a goal would be feasible or beneficial to the Indian people. Until 1948, placer sands in India and Brazil were actually one of the world's two main sources of rare-earth metals, and India is the holder of the world's 5th-largest rare-earth deposits at an estimated 5% of global deposits. But India mined only 3000 tons of rare-earths in 2020, due to the lack of a substantial electronics manufacturing industry within India until recently. Mining and processing is almost wholly under the management of the public-sector corporation Indian Rare Earths Limited (IREL), which focuses primarily on producing materials for nuclear energy rather than on the rare-earths used in technology. India's main deposits of rare-earths are also its main deposits of nuclear fuels such as thorium, meaning access to these deposits is monopolized by IREL under the Atomic Energy Act of 1962. As recently as 2019, the GOI amended the Atomic Minerals Concessions Rules to

[24] https://e360.yale.edu/features/china-wrestles-with-the-toxic-aftermath-of-rare-earth-mining

[25] https://oxford.universitypressscholarship.com/view/10.1093/oso/9780190670931.001.0001/oso-9780190670931-chapter-5

[26] https://www.bloomberg.com/news/articles/2019-05-31/china-has-a-rare-earths-plan-ready-to-go-if-trade-war-deepens

effectively nationalize beach sands containing monazite (a silicate containing trace amounts of uranium and thorium), extending IREL's monopoly on sand operations to nearly all of India's coastal areas.[27] IREL, with no incentive to build processing facilities, largely exports these rare-earth ores to Chinese refiners, and other firms which have attempted to produce in the area have stumbled on obtaining all the necessary licenses and permits. If the sector adjusts regulations around Indian rare-earth production to permit private operations in these deposits and incentivize investment in rare-earth refineries, then India could stand a chance of becoming a newly central rare-earths supplier in the global supply chain – a development which countries wary of remaining dependent on China for rare-earths access would sympathize with and even invest in.[28] Operations based on extracting rare-earths from byproducts of other industrial processes could even reduce the impact to the environment. However, if deregulation of the sector leads to the same large-scale informal open operations which China once relied on, subsidizing the growth of its industry through ecological damage, then the benefit will likely not be worth the cost to India's people and environment. And such operations would likely need enough government support to withstand dumping from China in the face of an emergent competitor.

India has various additional paths into gaining access to the materials its electronics manufacturing sector requires. Currently, millions of Indians work in the informal e-waste recycling and disposal sector – one of the most popular, yet hazardous, ways for the urban and rural poor to make a living. This sector both unnecessarily jeopardizes the health of those who participate and undercuts the competitiveness of formal e-waste disposal facilities, which largely restrict themselves to basic dismantling and segregation of parts. Coordinated investment into the e-waste disposal space could recover materials used in discarded devices at a higher rate, particularly rare-earths, and could provide better conditions for countless workers while reducing the sector's environmental impact.[29] India could also leverage its skilled talent pool to open new processing facilities for rare-earth ores from Indian-controlled mines in Africa and Latin America. India can follow international best practices for such resource investments to pursue local buy-in and to provide benefits to resource communities according to its own comparative advantages. While China, for instance, typically purchases mineral and refining rights through infrastructure investments, which synergize with its Belt and Road Initiative (BRI) while providing an outlet for the country's excess construction capacity, India could include innovations drawn from its suite of ICT-driven development initiatives to help sell its involvement to foreign governments and populations. Indian technical expertise could also be used to integrate the next generation of digital innovation in the mining sector, improving safety while reducing environmental impacts.[30]

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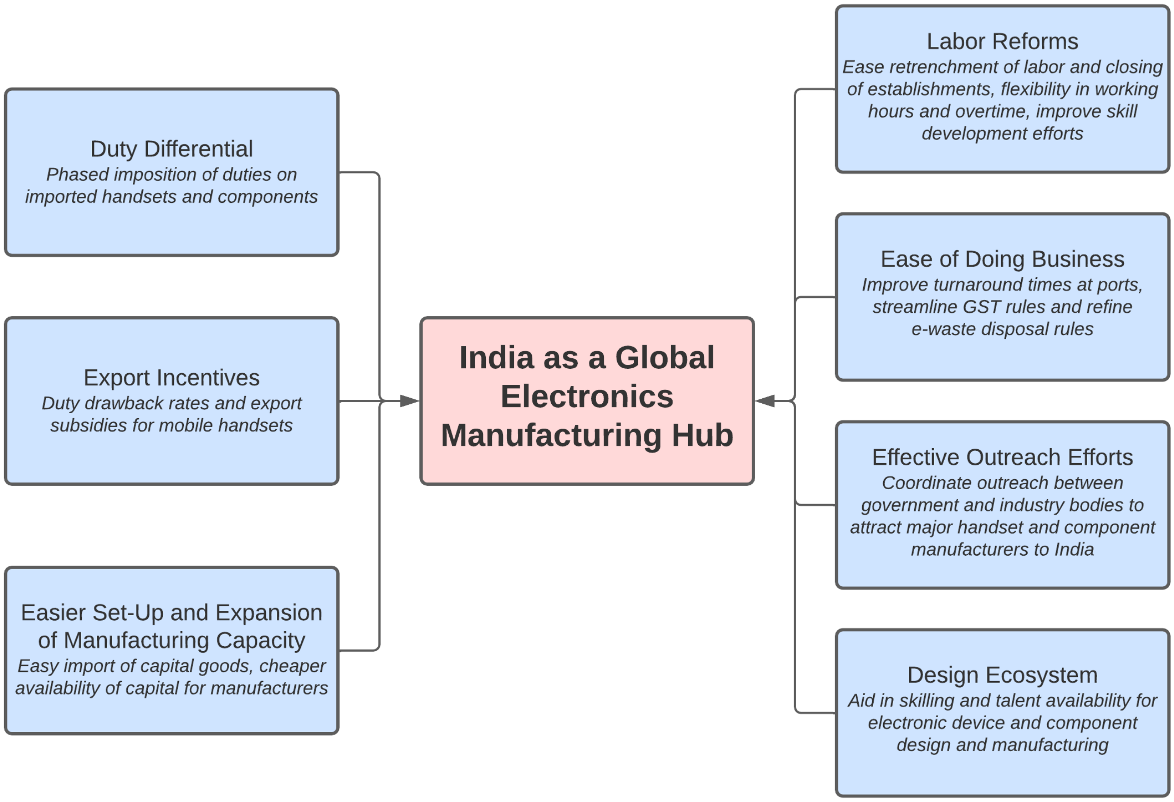
[27] https://www.firstpost.com/india/a-rare-earths-roadmap-for-india-seeking-atma-nirbharta-in-indian-technology-10270901.html

[28] https://www.deccanchronicle.com/opinion/columnists/280821/manish-tewari-the-rare-earth-metal-race-how-india-lost-it-to-china.html

[29] https://escholarship.org/uc/item/1cq3j0b0

[30] https://ccsi.columbia.edu/sites/default/files/content/docs/new-mining-technology-policy-options.pdf

A Robust and Cohesive ICT Supply Chain for India



ICEA's strategic vision for the development of Indian mobile manufacturing, released in 2017.

In 2017, ICEA published a brief roadmap on how India could achieve the status of a global electronics manufacturing hub. The ICEA outline included some policies the GOI was on the verge of implementing, such as import duties under the PMP and export incentives under the PLI. ICEA also suggested more general reforms beneficial for the entire manufacturing sector, like simplified import processes for capital goods, reform of labor regulations, and improvement of the overall ease of doing business. The remainder of ICEA's recommendations fall into the bucket of organizing an ecosystem within India specific to electronics manufacturing by expanding talent availability and increasing cooperation between the public and private sectors. At the time, ICEA estimated that India's smartphone industry could reach a value of 230B USD after adopting an export orientation, envisioning a path to manufacture 1.25B handsets within India by 2025 for worldwide usage and create 4.7 million jobs from APTP operations and component manufacturing alone.[31] As of today, these goals remain quite far off.

In the five years since the release of the ICEA strategic vision, India's electronics manufacturing sector has made substantial leaps in some areas and faced great challenges in others. Government policies have attracted substantial investments from multinational companies, both expanding the

[31] https://icea.org.in/icea-make-in-india/

size of the sector and retaining a greater share of manufacturing value within India. India today is a thriving hub for semiconductor design, and the electronics manufacturing industry as a whole has never played such central a role in the economy before. But Indian consumer electronics companies have struggled to introduce products that have gained substantial user bases, which could inhibit their ability to adequately invest in producing the ICT devices which will form and interface with the national digital infrastructure. And India remains far from securing reliable access to the strategic raw materials which its emergent, vertically integrated electronics manufacturing industry will demand in the very near future.

One of the first steps India can take to strengthen its electronics manufacturing industrial policy is to diversify the types of support offered to potential investors. Policy support so far has largely come in the form of subsidies, but many barriers to investment are non-monetary. For instance, electronics manufacturing requires uninterrupted power and water, but the electrical grid in parts of India including some manufacturing hubs remains prone to disruptions, surges, and blackouts. Fairly or not, images from the COVID-19 pandemic only cemented impressions held by some investors of a country lacking the baseline level of infrastructure necessary for successful high-tech manufacturing. Policy support for electronics manufacturing, then, could include extra infrastructure investment in industrial clusters or even dedicated sources of power and water. The government could also offer more varied types of financial support: government guarantees of corporate bonds for strategic facilities across the supply chain would increase investment by reducing investor risk, and Advanced Market Commitments (AMCs) would ensure investor returns by guaranteeing a purchaser for their goods.

India is well along the path of moving up the value chain in semiconductor manufacturing, thanks to the country's deep reservoirs of skilled talent and initiatives such as the ISM. According to MeitY head Ashwini Vaishnaw, "the biggest advantage India has is the entire design ecosystem…what we are offering in advance is a very clear 20-year roadmap where the focus is on generating that talent, nurturing that talent and making sure that as the industry grows, there are a sufficient number of well-trained engineers available for taking that journey forward." Joint ventures, through ISM or otherwise, hold great potential for nurturing that engineering talent by offering direct opportunities for skill and technology transfer. China, in fact, has been so cognizant of the power of joint ventures to boost local industry that it makes JVs with domestic Chinese partners mandatory in certain, largely high-tech sectors. India may not yet have the market power to compel international companies to make similar trades, but it would do well to expand JV requirements within its industrial policy portfolio.

Finally, India's entire electronics manufacturing industry is highly divided between various government bodies, research groups, and spheres centered on other industries. This has inhibited the development of strong, direct linkages along the supply chain from miners and processors to core manufacturers and all the way down to retailers and end users. R&D initiatives are duplicated, mineral exploration fails to prioritize crucial strategic materials, and research is not coordinated with production efforts and priorities. To rectify this, India should establish a new central commission responsible for managing the relationships across the electronics manufacturing supply chain. Rare-earth operations should be split off as independent entities with control over exploration and production, and regulations within the industry should be reformed to remove what barriers exist to refining these valuable minerals within the country for use by domestic manufacturers. These manufacturers should have direct lines of communication with top-tier Indian universities to make sure the domestic industry retains access to and a sufficient supply of elite talent. And R&D in the electronics space should be managed in coordination with domestic electronics manufacturers to minimize the bottlenecks that emerge between conception and production.

India has a golden opportunity to emerge as a major electronics manufacturer within the next decade. In doing so, it can develop an industry which will contribute substantially to the building of wealth within the country while providing the hard infrastructure needed for the construction of a digital Indian economy. And by making this digital economy more robust and resilient, the new domestic electronics supply chain will make India’s pursuit of core development goals in areas such as health and education that much more durable and sustainable. But the window will not remain open forever; action must be swift and decisive.

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