Establishing a High Tech Power Electronics Manufacturing Hub in Chhattisgarh

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1. Introduction

Appropriately termed as the "Revolution of the miniature" (Braun and Ernest, 1968), the Electronics industry since has propelled itself to occupy an immutable place in our everyday lives. Each year, the electronics industry generates an array of products and services increasingly used in nearly every human endeavor. Now deeply entwined in our social fabric, electronics products and systems now support critical aspects of communication, education, finance, recreation, and government. The competition in the field has exponentially increased leading to rapid investment and innovation, enabling transformation to what is referred as the "Digital Revolution".

1.1. The Electronic Market – Globally and in India

According to a 2017 report of The Business Research Company (TBRC) the global electrical and electronics manufacturing market is expected to reach $3 Trillion by 2020, with Asia Pacific as the largest market by geographic region and China the biggest market by country.

The demand for electronic devices in India is expected to rise from $80 billion in 2012 to $ 400 billion in 2020. The market is projected to grow at a compound annual growth rate (CAGR) of 24.4% during 2012-2020. The electronics sector consists of consumer and industrial electronics, computers, communication and broadcasting equipment, strategic electronics, and electronic components. The consumer electronics and durables industry is currently poised at about Rs. 340 billion.

The growth in the demand for telecom products in India has been outstanding, and as per the International Data Corporation (IDC) report[1], it was estimated that 152.5 million mobile phones were sold in 2019. With telecom penetration of around 10 percent, this growth is expected to continue, at least over the next decade. Penetration levels in other high growth products are equally high and the growth in demand for Computer/ IT products, auto electronics, medical, industrial, as well as consumer electronics is equally brisk. Combined with low penetration levels and the Indian economy growing at an impressive 7% per annum, the projection of a US$ 150 Billion market is quite realistic and offers an excellent opportunity to electronics players worldwide.

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[1] IDC India Report, Feb 2020 https://www.idc.com/getdoc.jsp?containerId=prAP46013620

While the Electronics sector in India is currently establishing its global role, there are several advantages that India offers that can be effectively leveraged to achieve higher growth: Manpower, Market Demand, and Policy and Regulatory Support. Yet, the demand of around 60 to 70% is met mainly by imports, which is a clear worry, with imports continuously rising faster than the local production. Successive governments have made attempts to expand the existing support program in order to make the underdeveloped electronics industry more competitive. The main focus is the establishment of production clusters, research and development, in particular, with the collaboration of foreign investors.

1.2. Electronic System Design and Manufacturing (ESDM) – Current Status in India

The Indian Electronic System Design and Manufacturing (ESDM) industry is one of the fasted growing sectors in the country market, and as per India Electronics and Semiconductor Association (IESA) estimates has grown at a compounded annual growth rate (CAGR) of 14 per cent from 2016-2019. It is expected to accelerate at a CAGR of 16.6 per cent between 2020 and 2025. The electronics production currently contributes 3.3 per cent to the economy. It will grow to $320bn by 2025. With additional measures, it has the potential to reach $410bn. This will be 8.2 per cent of India's GDP (gross domestic product) target of $5 Trillion by 2025.

As India is forecast to be among the world's top three countries in ESDM consumption, it's only natural that the electronics ecosystem is strengthened so that the country will rank among the world's top five countries when it comes to electronics production.

The ESDM industry in India is globally renowned for its consumption potential. Changing global landscapes in electronic design and manufacturing capabilities and cost structures have turned the attention of global companies towards India. Companies from around the world are looking to build local capabilities in India not just to serve the resident market but also cater to overseas markets. This has resulted in the development of indigenous capabilities across the ESDM value chain in India.

The different segments within the ESDM industry are:

- Electronic products
- Electronic components
- Semiconductor design
- Electronic Manufacturing Services (EMS) including testing and calibration

The first two represent products while the remaining refer to the services offered by the industry to domestic and export markets.

1.2.1. ESDM Growth Drivers

- Telecom equipment (including mobile devices), consumer appliances, automotive, industrial and strategic electronics applications will continue as the growth drivers for the Indian ESDM industry

- Significant growth achieved in the production of mobile handsets, accessories, LED TVs, LED lights and even some growth in component manufacturing.

- According to the Directorate General of Commercial Intelligence and Statistics (DGCIS), exports of computer hardware and peripherals and consumer electronics stood at US$ 198.04 million and US$ 234.19 million, respectively, between April and October 2018.

- Electric vehicles and connected mobility related applications have already opened up huge opportunities for power electronics devices and components, including power management semiconductors, etc.

- In the electric vehicle (EV) space, the desire for a longer driving range between charges, faster battery charging times, higher electronics integration for infotainment, safety and security, and other applications will drive tech advances, increasing the total electronics content of EVs.

- The Internet of Things (IoT), 5G and artificial intelligence (AI) are emerging as new growth drivers.

Box 1: ESDM Trends [2]

McKinsey Global Institute (MGI), shared insights into the upcoming wave of 12 technological developments, termed as the 'Disruptive Dozen', which will have the greatest impact on the way we live now, and have the highest potential to recast the business landscape in the coming decade. The 'Disruptive Dozen' includes mobile Internet, the automation of knowledge work, the Internet of Things (IoT), cloud technology, advanced robotics, autonomous and near-autonomous vehicles, next-generation genomics, energy storage, 3D printing, advanced materials, advanced oil and gas exploration and recovery, and renewable energy. These technologies are estimated to add between US$ 500 billion and US$ 1 trillion to India's economy, and will significantly improve the lives of people. Therefore, strengthening the capabilities of the Indian electronics industry to leverage the benefits of these disruptive technologies is the need of the hour.

[2] Navigating a world of Disruption, Jan 2019, McKinsey Global Institute
https://www.mckinsey.com/featured-insights/innovation-and-growth/navigating-a-world-of-disruption

1.3. Key Challenges facing the ESDM Industry

1.3.1. Net zero imports by 2020 – A distant dream

The electronics sector has been the focus of attention for the last decade and is widely recognised as one of the driving forces in a vibrant and modern economy. However, in 2018-19, the country imported US$ 50.85 billion worth of electronic goods. With imports still forming a large part of the Indian electronics manufacturing ecosystem, the plans for Net Zero imports by 2020 is indeed a distant dream.

1.3.2 Dependence on China

Against total imports of $50.85 Billion, China accounted for over $ 20 Billion (around 40% of Total Electrical and Electronics imported). This raises a serious concern, especially considering the demand to rapidly increase to around US$ 400 billion by 2023-24.

Refer Table 1 below, which highlights the sub category wise imports of electrical and electrical components from China. The Telecom equipment (which includes electrical parts for Telecom and mobile handsets) was the highest contributor in 2018-19 (43%), although the share has drastically dropped from 64% in 2014-15. This could be attributed to the local manufacturing of mobile handsets in India, with brands like Samsung, Realme and Xiaomi having their local manufacturing presence.

	2014-15	2015-16	2016-17	2017-18	2018-19
Telecom Equipment and Mobile Handsets	64%	59%	59%	61%	43%
Automatic Data Processing Machines	21%	18%	15%	15%	18%
Integrated Circuits and Micro Assemblies	3%	3%	3%	3%	17%
Diodes, Transistors and other Semiconductors.	6%	14%	17%	15%	12%
Electric Accumulators	2%	3%	3%	3%	6%
Transformers, Converters and Inductors	4%	3%	3%	3%	5%
Total	100%	100%	100%	100%	100%

Table 1 Electrical and Electronic Imports from China (by Sub Category); Source: Exim Bank

It is interesting to note the substantial increase in IC Chips, Micro assemblies (5X times increase) and Semiconductor components (2X times), suggesting the increased demand for these items in India, with little or no manufacturing taking place in India.

The recent Indo- China standoff has resulted in many of the Industry bodies calling for a ban of Electronic Imports from China. However given the current dependency for certain components as highlighted above, and local manufacturing yet to take off for these components, policy makers would need to consider the option of evaluating other countries (Taiwan, Japan, Singapore, Malaysia, etc.), whilst working towards a long term strategy for local manufacturing of semiconductors.

1.3.3. "Assemble in India" VS "Make in India"

Whilst there has been progress to increase manufacturing in India, there are concerns that India should not become a mere 'assembly hub". Although many companies have started manufacturing in India but for the majority of the components, the industry is highly dependent on imports.

1.3.4. Dump yard of used goods:

With the import of second-hand products made legal in the country vide a notification in May 2019, tech companies can now import second-hand devices, whether refurbished, repaired or reconditioned to India, subject to clearance from the Directorate General of Foreign Trade (DGFT) and Bureau of India Standards (BIS). This is likely to increase the concerns of India becoming a dump yard of used electronics goods, especially refurbished mobiles and appliances.

2. National Policy on Electronics

Successive governments have worked towards propelling India as a powerhouse for ESDM manufacturing given the growing demand and strategic importance. The National Policy on Electronics (NPE 2012) announced in 2012 set forth the vision to develop a globally competitive ESDM industry to meet the country's needs and serve the international market.

2.1. NPE 2012 Key Highlights

Some of the salient objectives of the NPE 2012 were as follows:

- To create an eco-system for a globally competitive Electronic System Design and Manufacturing (ESDM) sector in the country to achieve a turnover of about USD 400 billion by 2020 involving investment of about USD 100 billion and employment to around 28 million people at various levels.

- To build on the emerging chip design and embedded software industry to achieve global leadership in Very Large Scale Integration (VLSI), chip design and other frontier technical areas and to achieve a turnover of USD 55 billion by 2020.

- To build a strong supply chain of raw materials, parts and electronic components to raise the indigenous availability of these inputs from the present 20-25 per cent to over 60 per cent by 2020.

- To increase the export in ESDM sector from USD 5.5 billion to USD 80 billion by 2020.

- To significantly enhance availability of skilled manpower in the ESDM sector. Special focus for augmenting postgraduate education and to produce about 2500 PhDs annually by 2020.

Major initiatives taken under the NPE 2012 included the development of Infrastructure through special packages like Modified Special Incentive Package Scheme (M-SIPS), creation of 20 Electronics Manufacturing Clusters (EMC), and set up of Centres of Excellence (E.g. National Centre of Excellence in Large Area Flexible Electronics (NCFLEX)-IIT Kanpur, National Centre of Excellence for Technology on Internal Security (NCETIS) – IIT Mumbai) and Incubators E.g. Electropreneur Park, New Delhi for IP creation and Product development in the sector).

The NPE 2012 also facilitated the promotion of DMEP's (Domestically Manufactured Electronic Products) through special preference in Government procurement, along with Tariff rationalization to promote domestic manufacturing including Mobile Handsets, Televisions, Electronic Components, Set Top Boxes, LED Products, Medical Electronics, Solar PV Cells and Microwave Ovens.

Further, an Export Promotion impetus was provided through Brand-building and promoting investment and export of electronic goods through Market Access Initiative (MAI) Scheme and promotion of the Brand "India" Label in the overseas market.

Introduction of the Phased Manufacturing Programme (PMP) for promotion of domestic manufacturing of mobile handsets and sub-assemblies/ parts, which has enabled India become the World's second largest manufacturer of mobile phones (despite the exit of Nokia's manufacturing in 2014).

The NPE also enabled Skill development for ESDM through Sector Skill councils and focused programs like Special Manpower Development Program for Chips to System Design (SMDP-C2SD) aimed to develop more than 50,000 Specialized Manpower in the area of VLSI/System Design.

2.2. NPE 2019- Salient Changes over NPE 2012

The schemes and programmes that were launched by NPE 2012 successfully laid the foundation for a competitive Indian ESDM value chain. The government now seeks to build on that with an upgraded policy called the NPE 2019.

Some of the salient changes of NPE 2019 vis-a-vis the NPE 2020 are as follows:

- Whilst the NPE 2012, aimed to achieve US$ 400 billion in revenues in the domestic electronics manufacturing industry by 2020, NPE 2019 is designed to extend the deadline and achieve the revenue target by 2025. This will include targeted production of 1 billion mobile phones by 2025, valued at US$10 billion, including the export of 600 million mobile phones.

- In line with the plans for Industrial Revolution 4.0 (IR 4.0), NPE 2019 aims to create an ecosystem favorable for entrepreneurship in emerging technologies like the IoT, artificial intelligence (AI) and machine learning with a focus on solving real-world problems and boosting applications in areas such as health, smart city automation, defence, and agriculture.

- NPE 2019 goes beyond the scope of NPE 2012, aiming to achieve US$ 55 billion in revenue in the very-large-scale integration (VLSI), embedded chip design and embedded software industries by 2020. It also aims to build up a strong raw material, parts and electronic components supply chain that will increase the local supply of these inputs from 20-25 per cent in 2020 to 60 per cent by 2025. It is fair to expect a revision on these targets post the COVID 19 pandemic.

- In a major fillip to the Semiconductor Industry, NPE 2019 focuses on supporting natively designed integrated circuits, on-chip systems, semiconductor IP licences, and all related systems and application software products, including software IP licences, where IP resides in India. The policy aims to support the Indian fabless industry through venture capital (VC) financing and through active market interventions driven through specialised agencies, including the establishment of the Indian Fabless Semiconductor Venture Capital Fund.

A summary of the key differences between the NPE 2012 and NPE 2019 has been highlighted in Table 2 below.

Focus Area	What NPE 2012 had promised	What NPE 2019 aims for
1. Electronics design ecosystem	Aimed to achieve $400 billion in revenue in the domestic electronics manufacturing industry by investing $100 billion in electronic system design and manufacturing by 2020.	Same target with revised deadline. Aims to achieve the old target now by 2025.
2. Mobile manufacturing	Aimed to build up a domestic manufacturing capacity of 500 million mobile phones per year by 2019, with an estimated turnover of around US$ 46 billion.	Aims for a capacity of 1 billion mobile phones by 2025, with a turnover of US$ 183.06 million (₹ 13 trillion) including the export of 600 million devices worth ₹ 7 trillion.
3. M-SIPS	Provided 25 per cent capital subsidy for the electronics industry in non-special economic zones and 20 per cent for those in the SEZ.	Plans to replace the M-SIPS program with programs such as interest subvention up to 4 per cent and credit default guarantee up to 75 per cent.
4. EMC	Aimed to promote around 200 clusters across the country.	No new target has been declared. Govt. intends to provide support for infrastructure development through the formulation of a new scheme or suitable modifications in the existing EMC scheme
5. EDF/startups	Planned to set up incubators and Centres of Excellence (CoE).	No further announcements about incubators and CoEs have been made. There are plans to provide the requisite support in the form of electronic design automation (EDA) tools and FAB support for early stage startups.
6. Exports	Aimed to increase exports from US$ 5.5 billion in 2012 to US$ 60 billion by 2020.	No new export target has been set. Aims to increase the rate of duty drawback for the electronics sector rebate of state levies (ROSL) and other taxes/duties for which input tax credit is not available.

Table 2 NPE 2019 Vs. NPE 2012 at a glance; Source: Baisakhi Dutta, Electronicsb2b.com

Whilst the successive NPE's have been right in intent, the progress made has been considerably slow. The target deadlines of achieving $400 Billion by 2020, has now been revised to 2025. Further the decision to invest in Semiconductor FAB as per the NEP 2012, has not gained any traction. Also against a planned target of 200 EMC's, a meagre 20 EMC's have been set up as on 2019, and the new NPE does not mention any targets with implementation deadlines.

Moreover the NPE in its new avatar continues to depend highly on mobile phone manufacturing, an industry where India is already the 2nd largest manufacturer globally. The NPE 2019 has set an ambitious target of manufacturing goods and offering services worth $350 Billion by 2025 and half of it is expected to come from a robust mobile phone sector. The dependency on imports assumed to be due to the Mobile Industry is rightly placed but fraught with underestimating the growth in the India's sunrise sectors viz. Electric Vehicles, Solar PV's and other Power electronic equipment for Data Centers, 5G base stations which require a focused effort and strategy to foray into high voltage semiconductor devices.

2.3. Way Forward on NPE

The Implementation of the various Schemes/ Programmes under the aegis of the NPE 2012 has enabled consolidate the foundations for a competitive Indian ESDM value chain. It is now proposed to build on that foundation to propel the growth of ESDM industry in the country. Besides the economic imperative, focus on electronics hardware manufacturing up to the integrated circuit or chip level is required due to the growing security concerns, further acerbated by the recent Indo- China border skirmish,

With rising imports of Electronic components from China, as highlighted earlier, it is imperative that policy makers map future opportunities in the ESDM industry, with the current component manufacturing capacity available in India. As per market estimates and NPE 2019 targets, the Indian Electronics Industry is likely to grow from $ 120 Billion in 2019 to $ 400 Billion by 2025.

Refer Table 3, which indicates that Mobile phones and Consumer Electronics are likely to lead the demand, with increased penetration and demand, and contributing to 68 % of Total Electronics demand.

Electronics Production	2019 ($ Billion)	2025 - Est ($ Billion)
Mobile Phones	28.8	170
Consumer Electronics	26.4	100
Strategic Electronics	14.4	25
Computer Hardware	8.4	20
LEDS	2.4	10
Industrial /Power Electronics	39.6	75
Total	120	400

Table 3 Market Estimates for Indian Electronics 2025; Source: NPE 2019 and Market Estimates

However, these estimates appear to be bullish, especially on the demand projection for Mobile phones, despite the hard push and focus on this segment by the successive NPE's. Whilst investment into Consumer Electronics manufacturing has risen, there is likely to be a 5X growth in demand, due to increased penetration, and multiple ownership per household of TV's and Home Appliance products.

Whilst Industrial/Power Electronics is projected at $ 75 Billion, it can be safely estimated that this segment would get a further boost due to 5G, Internet of Things (loT), Artificial Intelligence (Al), Machine Learning, Virtual Reality (VR), apart from the growing demand for clean energy powered by Electrical vehicles and Solar PVs. The estimates for these applications alone are likely to be $ 800 Billion by 2030.

3. India Could Become a Major Hub for Power Electronics

The power electronics market is growing because new applications are supplementing a steady demand from traditional industrial companies. The growing sectors include power electronics used in wind turbines to match the variable power produced by the turbine generator to the grid; small inverters used for solar panels to change direct current into alternating current for grid and household use; power electronics for electric vehicles to control the electric power from the batteries; and smart grid applications that allow utilities to control power flows.

The market size estimates for the power electronics industry range from $20 billion for semiconductor devices only, to $70 billion if power supplies built around power semiconductors are included.[3] Globally, the Power electronics landscape has been changing continuously due to global macro factors like Climate change, Government regulations and subventions, technology advantages like Big Data, Artificial Intelligence (AI), IOT, along with multiple adjacent applications being developed. Multiple new applications like Solar, EV's, and charging stations have moved from being niche market applications to offering huge potential. (Refer Figure 1)

Power electronics is application driven, not technology driven, unlike other 'More than Moore' electronics areas. In recent years this market has grown thanks to megatrends such as the arrival of the digital era or environmental issues. As an example, the EV/HEV segment is driven technologically by CO2 emission reduction targets, higher efficiency requirements or less dependency on the oil industry.

[3] Power Electronics Industry Analysis, Bert Markgraf,2019, https://smallbusiness.chron.com

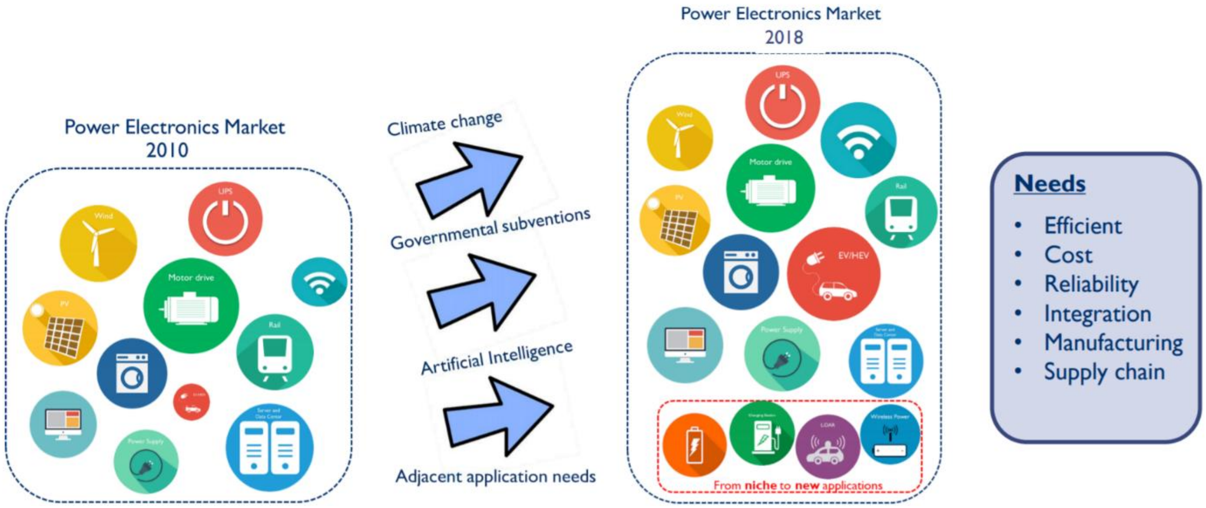

Figure 1 Changing Landscape of Power Microelectronics and New Applications; Source: GaN and SiC power device: Market overview, Dr. Milan Rosina, Semicon Europa 2018

3.1. Wide Band Gap Devices (WBG)

Whilst the traditional semiconductors used in Power electronics have been Silicon (Si) based, there are also new semiconductor-based materials at device level: the so-called WBG (Wide Band Gap), as Silicon Carbide (SiC) and Gallium Nitrate (GaN).

Wide bandgap (WBG) semiconductor materials allow smaller, faster, more reliable power electronic components and with higher efficiency than their silicon-based counterparts. These capabilities make it possible to reduce weight, volume, and life-cycle costs in a wide range of power applications. Harnessing these capabilities can lead to dramatic energy savings in industrial processing and consumer appliances, accelerate widespread use of electric vehicles and fuel cells, and help integrate renewable energy onto the electric grid.

WBG semiconductors permit devices to operate at much higher temperatures, voltages, and frequencies—making the power electronic modules using these materials significantly more powerful and energy-efficient than those made from conventional semiconductor materials.

Achieving high power conversion efficiency requires low-loss power semiconductor switches. Today’s incumbent power silicon (Si) based switch technology includes metal oxide field effect transistors (MOSFET), Insulated Gate Bipolar Transistors (IGBT) and Thyristors. Si power semiconductor devices have several important limitations:

- **High Losses:** The relatively low silicon bandgap (1.1 eV) and low critical electric field (30 V/µm) require high voltage devices to have substantial critical thickness. The large thickness translates to devices with high resistance and associated conduction losses.

- **Low Switching Frequency:** Silicon high voltage power MOSFETs require large die areas to keep conduction losses low. Resulting high gate capacitance and gate charge produce large peak currents and losses at high switching frequencies. Silicon IGBTs have smaller die than MOSFETs due to utilization of minority carriers and conductivity modulation, but the relatively long lifetime of minority carriers reduces the useful switching frequency range of IGBTs

- **Poor High-Temperature Performance:** The relatively low silicon bandgap also contributes to high intrinsic carrier concentrations in silicon-based devices, resulting in high leakage current at elevated temperatures. Temperature variation of the bipolar gain in IGBTs amplifies the leakage and limits the maximum temperature of many IGBTs to 125°C.

3.2. Silicon Carbide (SiC) vs. Gallium Nitride (GaN)

Silicon Carbide (SiC) and Gallium Nitride (GaN), both start with a large fundamental advantage over Silicon (Si) in the power conversion market. The devices can be made much, much smaller in size for the same relative voltage and current handling capability. As compared to SiC, GaN has had slow adoption because of cost, yield, and reliability concerns. It is certainly theoretically capable of switching at higher speeds than SiC or Si, with its much higher electron mobility. But GaN thermal conductivity is lower than that of Si, so its power density potential is limited.

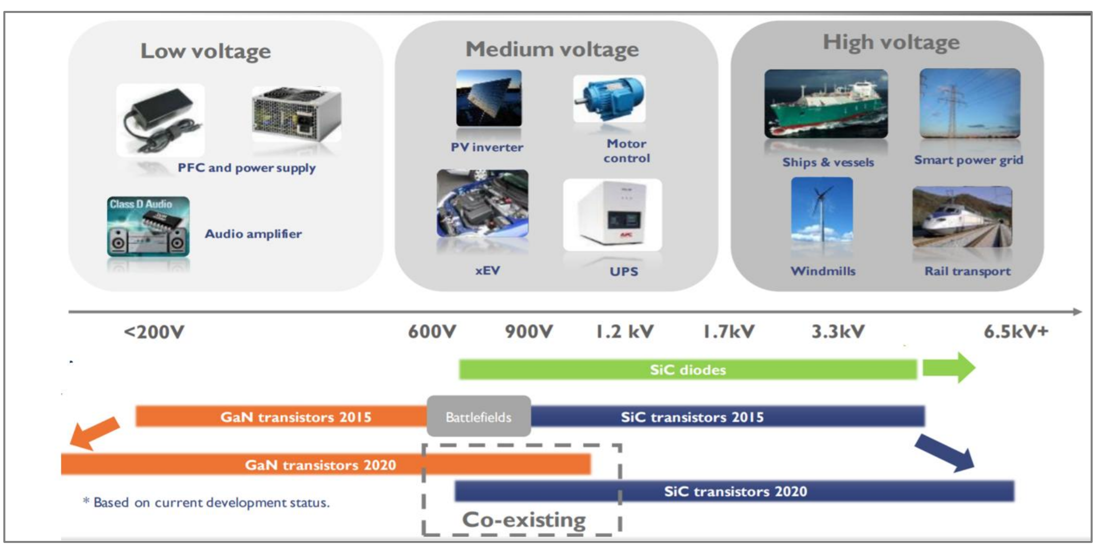

Figure 2 Power Electronic applications across different voltage range; Source: Yole Development 2018

As illustrated in Figure 2, SiC devices are commonly used at around 650 V through 1.2 kV and higher, while GaN is limited to around 650 V where it struggles to compete with less expensive, more robust, and more mature SiC offerings at the same voltage. SiC addresses the IGBT market at high powers and voltages, and GaN targets the lower-power but higher-volume and cost-sensitive markets of Si MOSFETs. These applications all demand WBG benefits – potential higher efficiencies and smaller size, but inexpensive and reliable, and ideally second-sourced. SiC is well established in the supply chain. SiC parts are available even from high-service distributors, whereas GaN parts have yet to become mainstream. The market analysis firm IHS Markit predicts this relative split in usage will remain into the mid-2020s, with the combined WBG market reaching $3.5B, of which GaN will represent only about $500M.[4]

3.3. Silicon Carbide (SiC) Semiconductor - Game changer for Indian ESDM

Having missed the first electronic revolution in the 1980s and the semiconductor fabrication opportunity in the 1990s, India can hardly afford to miss the emerging opportunity in Silicon Carbide (SiC), offered by Electric Vehicles (EV) and Solar PV. India needs to right in midst of this transition and then, target to achieve pole position in this sunrise industry. This would be of key strategic importance given India's objective to create and develop a "Make in India" Electronic devices Industry, with reduced dependence on imports, especially from China.

Apart from EV and Solar PV, there are other opportunities in the High Voltage – High Temperature applications viz., Data Centres, Industrial Motor applications, 5G base stations, Smart Agriculture and Irrigation with high scope and potential for SiC. This would enable India to be an active player across the semiconductor value chain in the "Next generation power devices" market. Table 4, below summarises the Top 4 opportunities for SiC in various applications. The market for these applications, is estimated to be around $ 700 Billion by 2030, with the devices market expected to contribute nearly $ 80 Billion.

Table 4 Market Estimates for Applications, Source: Research and Markets, NITI Ayog, Allied Market Research Solar Energy Market

Application	2020	2025	2030
Electric Vehicles	$ 5 Mn	$ 100 Bn	$ 300 Bn
Solar Power	$ 22 Mn	$ 100 Bn	$ 180 Bn
Data Centers	$ 4 Mn	$ 15 Bn	$ 40 Bn
Industrial Machinery	$ 85 Mn	$ 120 Bn	$ 200 Bn
Total	**$ 116 Mn**	**$ 335 Bn**	**$ 720 Bn**

[4] Where SiC outperforms GaN, Lee Treschler, 2018, https://www.powerelectronictips.com

SiC chip production is currently split roughly equally among the United States, Japan, and Europe. The top seven SiC chip manufacturers, which combined have over 95% of the market share, are large, multinational companies that were already established in the SiC power electronic device space, and all have vertically integrated a significant portion of the value chain, including final systems integration/applications. Many new entrants in SiC chip manufacturing are SiC pure-players, producing only SiC materials, and are focused on processing devices, a single piece of the value chain.

Over the last several years, China has made significant investments in developing a local semiconductor industry. SiC has been included in this, with the government providing significant funding for development of SiC chip manufacturing. Chinese SiC chip manufacturers have begun to enter the market and are looking to scale up production. Typically, Chinese SiC chip manufacturers (as well as Chinese manufacturers of SiC substrates, epi-wafers, and systems) are not vertically integrated.

3.4. The Six Links for SiC

The "Synchronized Links of SiC", essential for creating a sustainable and competitive ecosystem to support the SiC India Story is represented in Figure 3 below:

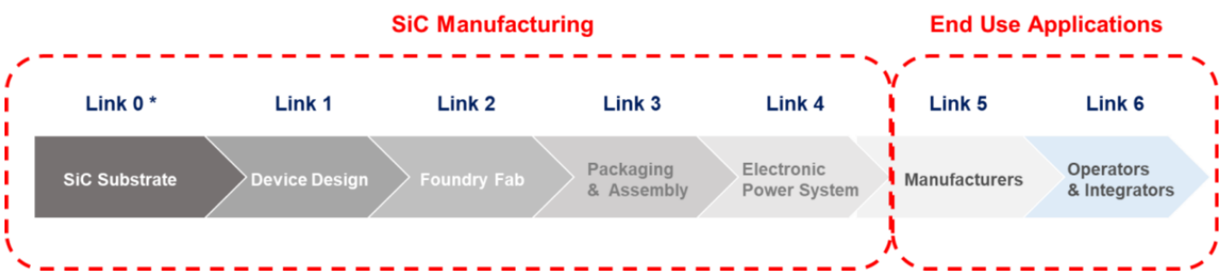

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Figure 3 Six Links to Create the Silicon Carbide (SiC) Value Chain

**Link 0: SiC Substrates are predominantly based in the USA, and India has no current capability on availability and technology. This Link is therefore not included in the scope of SiC Ecosystem.*

3.4.1. Link 1: SiC Device Design

Chip design or Device Design, is a process that creates the greatest value in the electronics industry. Until quite recently, chip design has indeed remained heavily concentrated in a few centers of excellence, mainly in the US, but also in Europe and Japan. However, fundamental changes have occurred over the last few years in the location of chip design that are signaling a growing geographical mobility. Of particular importance has been a massive dispersion of chip design to leading Asian electronics exporting countries.

Indian chip designers provide design services or work at the subsidiaries of global chip companies, especially US and European firms. Industry leaders believe India is becoming a ‘design store’ with a strong presence in Intellectual Property (IP) development, integration and embedded software services. The VLSI Society of India estimates the Integrated Chip design population in India to be around 11,000, while those working on the embedded software add up to 60,000. The presence of a strong System Design Ecosystem, and resources would enable India to successfully ramp up its presence in Design of SiC Systems for use in Power microelectronics.

3.4.2. Link 2: Foundry Fab

As a consequence of the rapid growth of SiC in Power devices, the industrial SiC supply chain is constantly evolving. For power devices, the foundry and IDM (Independent Device Model) are both developing. As per Yole Development, a strategic advisory firm, the foundry model is clearly developing, and the industry evolution is facilitating the SiC fab-less and fab-lite companies in launching SiC products and making the technology more accessible to the industry.

3.4.3. Link 3: Module Packaging and Assembly

State-of-the-art silicon packaging material systems can operate up to 175ºC which is incompatible with the limits of Si devices. WBG devices, which can operate at much higher temperatures (200-350ºC) and electric fields (10x than Si devices), requires updated packaging material systems to provide compatible high breakdown voltage strength, compatible thermal-mechanical characteristics for better coefficient of thermal expansion (CTE) matching with SiC material, and the capability of withstanding higher operating temperatures.

Driven by the emerging market, SiC device manufacturers have put together available resources to provide their products to meet users’ demand. SiC Power modules are commercially available from Wolfspeed, RHOM, GeneSiC, Infineon and SEMIKRON (Refer Figure 4). Both Wolfspeed and RHOM provide 2-level, half-bridge, and phase-leg modules. RHOM’s module is in an EconoDual package, which is similar to the state-of-the–art IGBT package

3.4.4. Link 4: Electronic Power Systems (EPS)

Link 4 comprises all the system control components required to power the drive. This layer offers the highest level of value addition and includes two key components viz. Permanent Magnet (PM) motors and Li-Po (Lithium – Polymer) Batteries, in addition to Extenders, Gear Box, Reducer, and other major components.

Figure 4 Full SiC Module Examples; Source: Power SiC: Material Devices, Modules and Applications Report, Yole Development, 2017

Permanent Magnet (PM) Motors:

WBG power device materials, such as silicon carbide (SiC), are drawing increasing attention due to a number of superior qualities they possess, such as high switching-speed, lower specific on-resistance, and higher junction operating temperature capability. The application of SiC in a motor drive inverter can reduce both switching and conduction losses, shorten dead time in a phase-lag, and increase switching frequency, etc. Hence, the SiC-inverter can provide higher efficiency and higher power density in comparison to its silicon (Si) inverter counterpart, which is benefit for the electric vehicles with limited capacity battery.

Aside for these inverter-level benefits, the SiC-inverter also affects features of the dynamic performance of a motor drive system, such as fast response, relative stability and robustness, etc. Because of its high efficiency and fast response characteristics, permanent magnet synchronous motors (PMSMs) are widely adopted in a host of high performance applications where low torque ripple, high efficiency, and remarkable dynamic response are highly demanded, such as dynamic positioning systems, machine-tool spindle electrical power steering and traction drives in electric vehicles, etc.

Lithium Polymer (Li-Po) Batteries.

Lightweight, flat, powerful, long-lasting, and astonishingly variable in design and capacity, are the many advantages that set Li- Po batteries apart. They stand out from other types of Lithium (Li) batteries in a whole range of other factors. They are also a recommended alternative to conventional lithium-ion batteries in countless applications. In small, flat, mobile devices in particular they can guarantee a constant energy supply.

According to market forecasts, sales of Li-based batteries will grow by some 15% each year until 2024. No practicable alternative to Li-ion and Li-Po batteries is currently known to science. Market analysts anticipate that the demand for Li-Po batteries in the automotive sector will grow enormously as a result of the growing spread of electrically powered vehicles.

3.4.5. Link 5: End Application Manufacturers

Another high value added and application driven layer would comprise manufacturers who would manufacture the end product; E.g. Electric Vehicles, Solar Inverters, 5G Integrated Modules, etc. based on end consumer needs and specifications. This link would enable application companies to design the end product, based on the inherent advantages of SiC modules (lesser space, lighter weight and enhanced performance). Opportunities exist for EV manufacturers to reduce cost substantially through use of alternate materials in lieu of traditional materials used in ICE (Internal Combustion Engines) vehicles.

Indian Automobile manufacturers can also assess the huge potential to create "Tropicalised EVs" considering the temperature, road, and traffic conditions for the Indian market. The Tropicalised designs can find extensive use case applications for export markets in Africa, Indonesia, and other developing markets, with similar conditions.

3.4.6. Link 6: Integrators and Operators

The final layer and the most important is the customer layer of Integrators and Operators, the foundation of the entire SiC value chain. The operators influence the System Design and Architecture of SiC by clearly specifying the end use applications. The design of the final product by the manufacturers is also defined by the end use case scenario specified by these operators. An interesting venture that would define the future of Electric vehicles is ZEV (Zero Emission Venture), a Taiwan based Electric vehicle operator. The introduction of an electric taxi service is also in line with the Taiwanese government's plan to ban the sale of gas-powered motorcycles by 2035 and gas-powered cars by 2040.

Another area explored in this paper is the adoption of Intelligent Public Transportation Systems (IPTS). IPTS is a subsystem of Intelligent Transportation Systems (ITS), which aim to control public transportation networks, to maintain their performance, and to provide users (passengers and decision makers) with up-to-date information about trips and network operating conditions. To reach these aims, IPTS rely on several technologies that can be embedded within different control architectures.

The continuous innovation in this market has helped improve transportation management and reduce traffic congestion. Currently, the application in advanced traffic management systems (ATMS) leads the overall market. ATMS has been the most successful and adaptable system of ITS due to its different functions such as real-time traffic monitoring, traffic signal controlling, incident monitoring, automated warning, dynamic message sign monitoring, traffic camera monitoring, and road weather information monitoring. This has resulted in a wide utilization of these systems in many applications.

4. Establishing a SiC Based Power Electronics Ecosystem in India

Having established the potential for SiC Power Microelectronics, and the opportunity it would create for the Indian Economy, it is important to look at "Playbook" for executing this "Next generation technology" in India by having a well-defined "Game plan" across the 6 synchronised Links. It is imperative that we identify and define the scope of India's participation in the value chain (What?), along with defining the appropriate partners (Who?), and finally operationalising the value chain (How?).

4.1. What? – Business Models across Value Chains

Let's relook at the current models (Refer Fig 5 below) for power modules that exist globally. The scope of the SiC Value chain in this case doesn't take into account the Link 5 (Manufacturers) and Link 6 (Operators and Integrators).

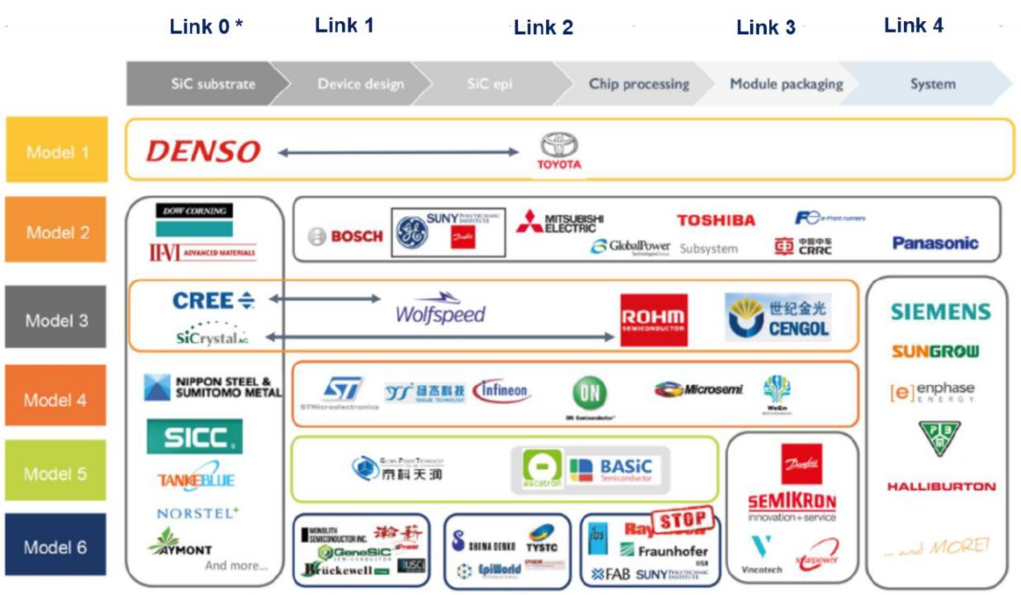


Figure 5 SiC Value Chain and Major Players, 2017; Source: Yole Development, http://www.yole.fr/

Whilst there are *six models* in practice in the SiC value chain for power modules, it is interesting to note that *Model 3 and Model 4 (IDM)* is dominated by market leaders (US and Europe) like Infineon, Cree and ST Microelectronics. The strategic decision to invest across the value chain, especially into Link 0 (Substrate) by Cree is to drive costs down through better yield and also ensure quality substrates. It is worthwhile to point out that Infineon, the current market leader has also moved into *Model 3* through an initial multiyear contract and subsequent acquisition of Siltectra GmBh for $140 mn in Nov 2018[5]

Model 3 is the most dominant model in the SiC power modules industry; it is also the most mature model with established players investing into the value chain for over a decade. In contrast, new players into the SiC Market (especially China and Taiwan) have opted for a strategy to have multiple players participate across the value chain to benefit from core competencies of each company i.e. Model 5 and Model 6. E.g. Episil, Taiwan is a high quality SiC epi "Pure Play Foundry and has integration into the value chain).

Models 1 and 2, mostly adopted by Japanese SiC players clearly demonstrates the backward integration into the value chain by popular consumer brands (Panasonic, Mitsubishi Electric, and Toshiba) to meet the product demand for new technology products.

Based on the above analysis, the following would be our key strategic recommendations:

1. With a large domestic market estimated at $ 480 Billion for EVs and Solar applications alone, India would need to necessarily invest across the value chain (barring Link 0 where currently, there is no competency, as also availability of raw material for SiC substrate. This would also help reduce its imports surplus due to sourcing of semiconductors, whilst also enabling create a strong SiC hub for newer applications and export demand.

   Choosing to invest into one or few links is not a sustainable strategy, a case in the point, as can be seen from our previous experience and learning from our limited participation in the Silicon (Si) semiconductor wave. Whilst, India had a presence in System Design i.e Link 1, yet we were unable to expand our presence as a semiconductor player globally.

2. *Model 6* with its focus on different companies across various stages of the value chain appears to be more suitable from the perspective of India, at least in the initial journey towards establishing SiC in India. It would not only enable companies to focus on their core competencies, but also minimize initial risks of investment for System Design companies to invest in Foundries and vice versa.

[5] Infineon Technologies- Press Release, Nov 2018, https://www.infineon.com

4.2. Who? - Identifying Potential Partners /Countries for SiC Technology Transfer

Whilst the SiC technology is currently available with US, Germany, France, Japan, China and Taiwan, the existing players in this arena have fully integrated themselves as IDMs with substantial investments into manufacturing and design globally. The role of India in the current ecosystem is limited to Link 1 i.e. System Design and Architecture, with companies like STM and Infineon Technologies having established their design centres.

There are multiple criteria that one would like to consider whilst evaluating partnership, the key being Business Model suitability for India, Level of IP and scope of Technology transfer with potential JV partners, competency in EV and Solar applications, and partnership with countries considering the geo-political scenario amongst other regulatory policies. A country wise comparison (Refer Table 5.) has been made to analyse countries with SiC technology know how and evaluate their suitability for partnership for SiC India.

Country	Models	Scope	Companies	Remarks
Japan	1,2 and 3	Mostly Integrated across Link 0 - Link 4 to meet end consumer demand and cater to new technology applications.	Denso (Toyota), Toshiba, Mitsubishi Electric, Rohm semiconductors. Nippon Steels and Sumitomo Nitrate are Substrate suppliers.	Large IP protection will limit its ability to transfer technology. Also majority of the SiC players are end consumer companies with backward integration to meet existing market demand and develop new applications. Rohm, a specialist semiconductor company unlike the other players, has already significantly invested into Japan and China.
Europe (Germany, France)	4	High Focus on Product Development. Integrated from Link 1-4	Infineon Technologies (Siemens) ST Micro electronics	Market leaders in SiC. Device makers like Infineon Technologies and ST Microelectronics own some key patents but do not necessarily have strong IP leadership. Therefore ability to transfer technology through JV would be limited in scope. Further, multi-billion dollar investments committed for the next 5 years anticipating a ramp up in demand, limiting scope of new investments.
United States	4	High Focus on Product Development Integrated from Link 1-4 and support to Manufacturers (Link 5)	Cree (Wolfspeed) Dow Corning (Substrates)	Similar to Infineon, Cree /Wolfspeed have key patents but do not necessarily have strong IP leadership. US dominates the supply of SiC Substrate. Technology Transfer would be limited to Link 1- System Design) due to committed investments in China

China	5and6	Mostly not integrated. "Pure Play" SiC players with specialists across links	CRCC, SICC, Global Power Technology Epi World International Co., Ltd.	Though a relatively new player into SiC, China offers High potential for investment into India considering competencies in EV and Solar applications. Potential investment opportunities in Link 5 with EV and Solar manufacturers. However scope of technology transfer will be limited due to geo political and security concerns.
Taiwan	5and6	"Pure Play" SiC players with specialists across links	Episil, GrenTech Energy, ITRI, Hestia	Taiwan has been a long-standing R&D player in SiC MOSFETs. High competencies on EV and Solar applications, especially in Link 1. Expressed interest to partner India for SiC technology.

Table 5 Country/Region wise SiC Players and Scope for Partnership/Investment in SiC India.

The following are the strategic considerations emerging from the above analysis.

1. Market leaders like Infineon Technologies (Germany), Wolfspeed (US), Rohm Semiconductors (Japan) and ST Microelectronics (France) have committed significant investments in SiC technology ahead of the curve in anticipation of a ramp up in demand. These companies are unlikely to invest or benefit from a transfer of technology to create a new ecosystem. Whilst these companies have already presence in India through System Design (Link 1), they would be unlikely to invest into the other value added links essential to transform India into a global SiC Hub.
2. Whilst Japan has been an early adopter of the SiC technology, the majority of companies (Mitsubishi Electric, Toshiba, Panasonic) have vertically integrated backwards to meet the technology demands of their existing customer market, and Product development for new applications. Also with the highest IP patents in the SiC space, these companies are unlikely to engage with a JV for technology transfer.

3. Whilst China has got off to a late start in SiC, they have made considerable progress. However, given the current geo –political situation with China, security concerns cannot be overlooked raised, since the SiC technology could have multiple new applications including Defence.

4. With the presence of "Pure Play" SiC players, and suitability of Model 6 for India, Taiwan is best suited to approach for potential JV partnership and establishing SiC competency in India. Taiwan. A Joint venture (JV) across the 4 layers would not only ensure complete technology transfer including IP, but also would enable create the required ecosystem for SiC based Power Microelectronics devices for use in multiple sunrise industries like EV, Solar PV, Data Centres, 5G base stations, Industrial and Smart Agricultural systems.

Economic cooperation in areas of trade, investment and industry between India and Taiwan has been very close in recent years. Bilateral trade has grown nearly five-fold from US$1.19 billion in 2001 to more than $5 B in 2016. During the same period, India's exports to Taiwan increased from $550 M to $2.2 B, while India's imports from Taiwan increased from $640 M to US$3.8 B (1.1%) in 2018. The bilateral trade relationship is further enhanced by frequent exchanges of visits by business delegations.

The Indian and Taiwan ESDM value chain synergy can be summarized in business to business (B2B) and business to government (B2G) opportunity areas. India's huge domestic market is a huge big attraction. Taiwan's hardware and technology strengths and India's software power and recent thrust on manufacturing make them ideal partners.[6]

4.3. How? – Operationalising the SiC Value Chain

Having answered critical questions above, in terms of the Business Model focusing on "Pure Play SiC" companies with individual competencies across the value chain (Business Model 6), and Second, shortlisting the countries for SiC technology transfer (Taiwan), it is important to highlight the Operationalisation plan for (Indo- Taiwan JV).

Figure 6 below, represents the proposed model suitable for SiC transfer of technology from Taiwan, and India providing the land, labour and the necessary Ecosystem required for manufacturing of SiC based Power modules, including end products. These products (e.g. EV and Solar PV Inverters) would cater extensively to meet the large domestic demand, as well as cater to Export markets.

[6] India- Taiwan, Partners in Success, 2019, http://www.mmindia.co.in

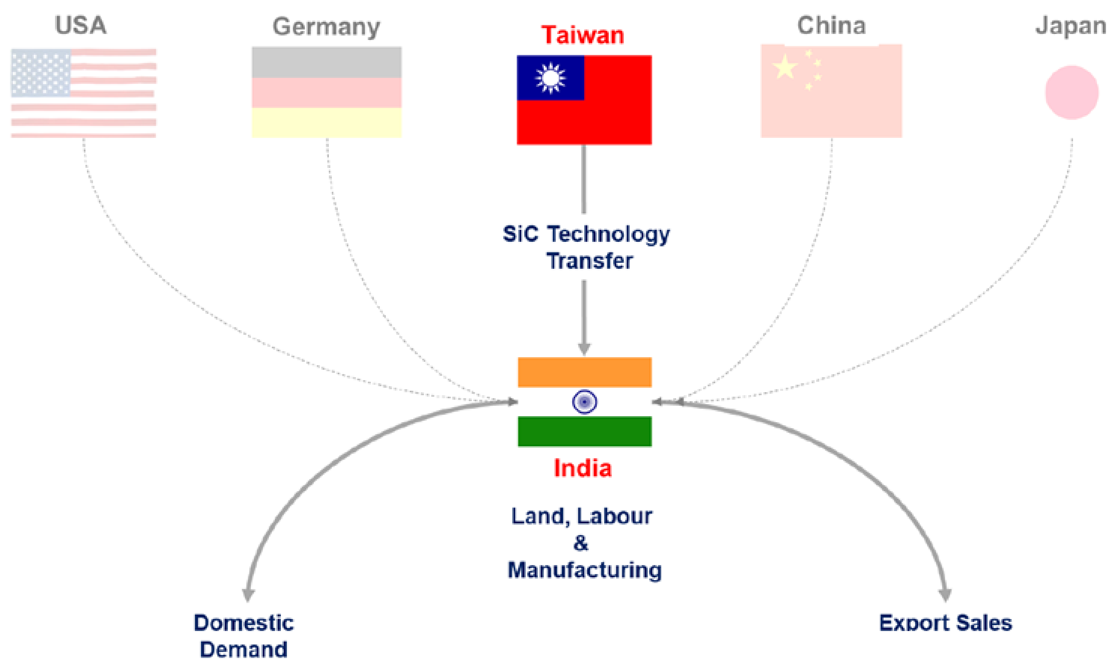


Figure 6 Silicon Carbide (SiC) – Possible Routes of Technology Transfer to India

4.4. How much? – Investments

Having defined the crucial links of the SiC value chain, we detail the next steps to create and establish the SiC manufacturing Hub. It is imperative to point out that Phase 1 investments would be limited to Link 1 – Link 4 (SiC Manufacturing), with an assumption that the investments into SiC would cater to the immediate demand of end application manufacturers (Link 5), and potential aggregators (Link 6). Establishment of a facility and investments for dedicated manufacturers and aggregators can be evaluated in Phase 2 and 3.

Focus on EV and Solar in Phase 1, given they contribute 65% i.e. ($ 480 Billion by 2030) to the over-all end use case applications. These are also high impact areas that dove tail with the initiatives and policies of the GoI to reduce carbon emissions through lesser electricity, no fuel emissions along with reduced dependence on fossil fuels. The remaining applications of Data centers, 5G, Industrial applications could be considered in Phase 2, post ratification of the application demand, and new applications (including Agriculture, Defence) can be evaluated in Phase 3.

1. In Phase 1, Invite 5 companies (Indo- Taiwan JV) to establish Link 1, i.e. System Design and Architecture focused on EV's (3 companies- Passenger, Personal LDV and Electric Bus) and Solar PV Inverter applications with SiC.

   The estimated investments in Phase 1 to establish the JV companies would be $ 25 Million ($ 5 million would be the cost to establish up each company). These companies can immediately cater to the SiC System Design requirements of the existing EV and Solar companies in India.

2. Identify potential Taiwanese partner to establish Link 2 i.e. the Foundry Fab/SiC Manufacturing facility in India. Potential foundries could be Episil and Vanguard, which are two of the leading SiC wafer manufacturing facilities in Taiwan. In Phase 1, we recommend that India will source the SiC wafers directly from Taiwan, whilst setting up its own SiC wafer facility in Phase 2.

   The estimated investments required to set up a Fab Foundry for SiC manufacturing is $ 150 Million. Further expansion can be considered in Phase 3 to meet additional demand requirements.

3. Packing and Assembly forming the Link 3, is a critical requirement in the SiC value chain and would require early investments in Phase -1. The packing facilities would also include an In-house Epoxy Plastic and Ceramic manufacturing facility required for the final assembly of the SiC modules.

   The Investments into establishing EV and Solar PV modules would be $ 100 Million.

4. The Electronic Power Systems required to drive the modules would be assembled in Link 4. This would include setting up of a manufacturing facility for Permanent Magnet (PM) Direct Drive Motors, as well as a facility for Lithium Polymer (Li-Po) Giant batteries.

   The investment to set up this facility would be $ 100 Million. Subsequent expansion can be done in Phase 2 for another $60 Million to ramp up production in anticipation of additional demand.

5. As highlighted earlier, investments in Link 5 (Manufacturers) and Link 6 (Aggregators) can be planned in Phase 2 and 3 basis validation of demand estimation in the mid and long term.
6. Subsequent investments for increasing scope of applications and scale of production can be planned in Phase 2 and 3. The additional investments would be linked to the capacity being expanded, as well as the scope of applications.
7. It would be prudent to point out that investments into semiconductor technologies require repeated investments. As per National Renewable Energy Laboratory, USA (NREL)[7] the Gross Margins for a SiC VFD Module is estimated at 15-20%. As per the report, India has the advantage of cheaper labour as compared to USA, Japan, and Germany and also is lower in comparison to China.
8. The rationale for semiconductor investment is strengthened by India's significant semiconductor GDP multiplier (Refer. Fig 8). The GDP multiplier for 1$ of technology investment is expected to be 21-23 X)[8]

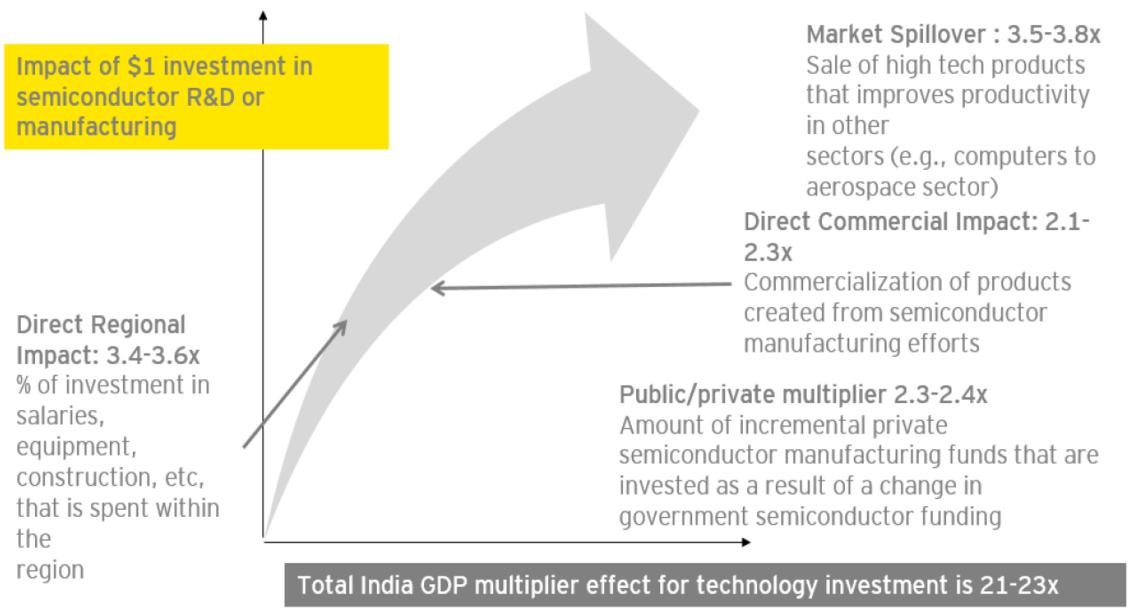


Figure 7 India GDP Multiplier for 1$ investment into Semiconductors; Source: Ernst and Young

Beginning from the invitation to set up a JV in Link 1 to the commercial production for domestic markets, and subsequently to the export markets across the entire SiC value chain has been summarized in Figure 8 below, along with proposed timelines.

[7] A Manufacturing and Supply Chain Cost Analysis of SiC https://www.nrel.gov
[8] GDP Multiplier for 1$ investment into Semiconductors, Source Ernest and Young

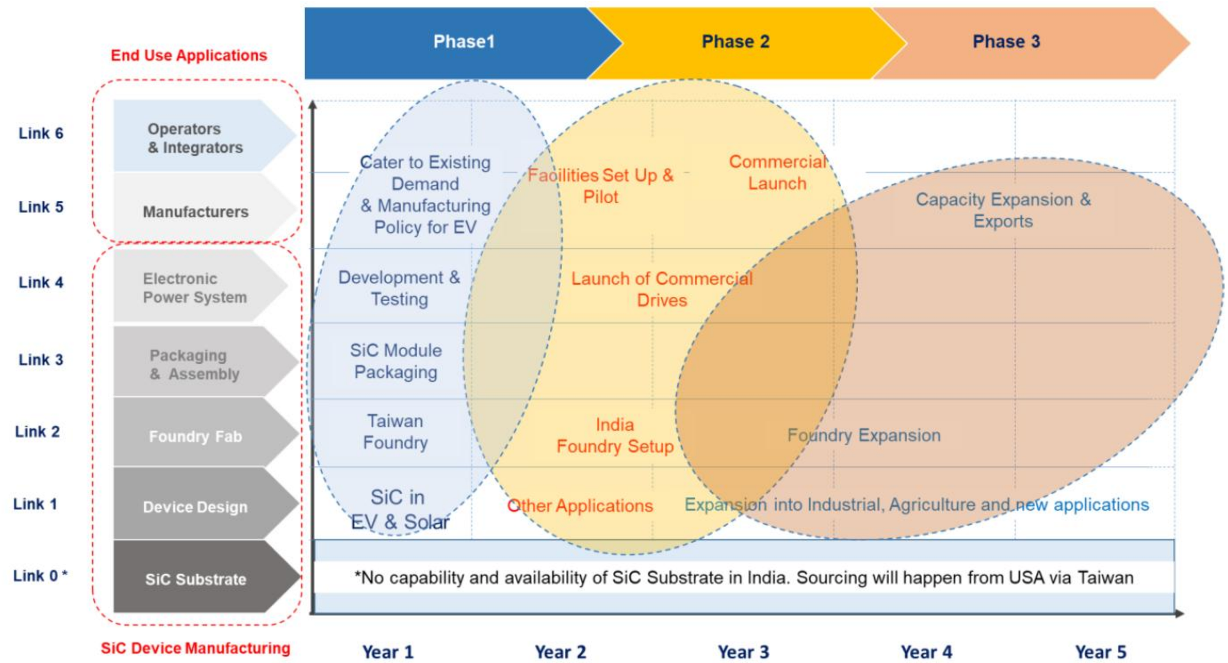


Figure 8 Roadmap for operationalising the SiC Value chain in India.

A summary with the proposed investments under each Link has been illustrated as per Table 6 below.

Table 6: Investments required to set up SiC value chain (in M$)

Sr. No	Investment Area	Phase-1	Phase – 2	Phase -3	Total
		(in $ Billion)			
1	System Design and Architecture	25	15	25	**65**
2	Fab Foundry		150	100	**250**
3	Packaging and Assembly	100			**100**
4	Electronics Power Systems	100	75		**175**
5	Manufacturers		150	100	**250**
Total Investments		**225**	**390**	**225**	**840**

5. Policy Recommendations for Building an SiC Ecosystem for India

To enable develop and establish India as a hub for SiC manufacturing, there are multiple policy interventions required to attract potential JV investments. Some of the recommendations are highlighted below.

5.1. Joint fund for R&D

A major characteristic of the ESDM sector is the importance of R&D and innovation due to velocity of technology change. As the half-life of technologies has been continuously reducing, it is important to focus on innovation. Governments of India and Taiwan should come together to seek proposals for joint applied R&D projects and other actions meant to generate new or expanded R&D-based partnerships between the two nations.

Department of Electronics and Information Technology (DeitY), Government of India and Taiwan could set up a joint fund and invite Indian and Taiwanese companies, researchers and academic institutes to submit proposals for joint research projects in the area of ESDM. Through this partnership, the Indian innovation ecosystem can be strengthened by leveraging the expertise from Taiwan. Under this partnership, the Indian companies can source high-end technology from Taiwan to innovate, whilst Taiwan can expand scales of innovation and reduce operational costs by investing in the joint R&D ecosystem.

5.2. Partnership on Skill development

In India, there is a huge demand for skilled workforce and has a great potential in terms of number of graduates every year, but they lack advanced competency level and skill sets, which adversely affect efficiency, productivity and delivery of goods and services. On the other hand, Taiwan has a limited but trained resource pool to develop a comprehensive set of capability to meet the electronics industry's talent needs.

Indian and Taiwanese Government could come together to establish a partnership for skilling initiatives and introduce standardization in skill development for ESDM industry. Singapore has already setup, the World Class Skill Development Center in Delhi, which acts as a national center of excellence for skill development in the fields of manufacturing, health care, medicine and construction. Similar skill development institutes can be created across the country to attain an increased number of resource pools in India.

5.3. Collaboration for implementing standards

It is important to create a common mechanism to develop and mandate standards and certification for electronic products and services to strengthen quality assessment infrastructure. Through a collaboration initiative between India and Taiwan to develop a set of standards that are acceptable to both the countries for electronic design, manufacturing and testing, the entry in each other's markets will become easier.

Under this partnership, certification by an agency of one country will be accepted by the other and hence, will lead to cost reduction as well as faster and easier access for companies wanting to tap the market. Furthermore, the removal of duplicate testing will open a wide market for manufacturers. Both countries can complement each other's ESDM industry, by creating same set of standards, since one has high demand but low supply while the other has low domestic demand but abundant supply of electronic products.

5.4. Trade, Commerce and Investment Relationships

Collaboration of small and medium enterprises is another focal area. Both sides have strengthened cooperation in important areas of policy sharing, technological assistance, innovation, entrepreneurship and business incubation, market development, as well as capacity and capability building.

Bilateral Economic Consultations Meetings between India and Taiwan are held annually and have been proven to be a success in bringing various mutual beneficial opportunities to both sides. Governments and industries of India and Taiwan will continue to engage closely in "Make in India", "Digital India," "Skill India," and "Startup India" initiatives for collective growth.

5.5. Science and Technology Cooperation

The MOU on Scientific and Technological Cooperation was signed between TECC and ITA in 2007. Another MOU of cooperation was signed between ROC (Taiwan) Academia Sinica and Indian National Science Academy in 2012. Bilateral joint meetings and academic seminars are held annually. As of the end of 2016, a total of 72 projects and joint proposals have been carried out while 16 seminars have been held bilaterally.

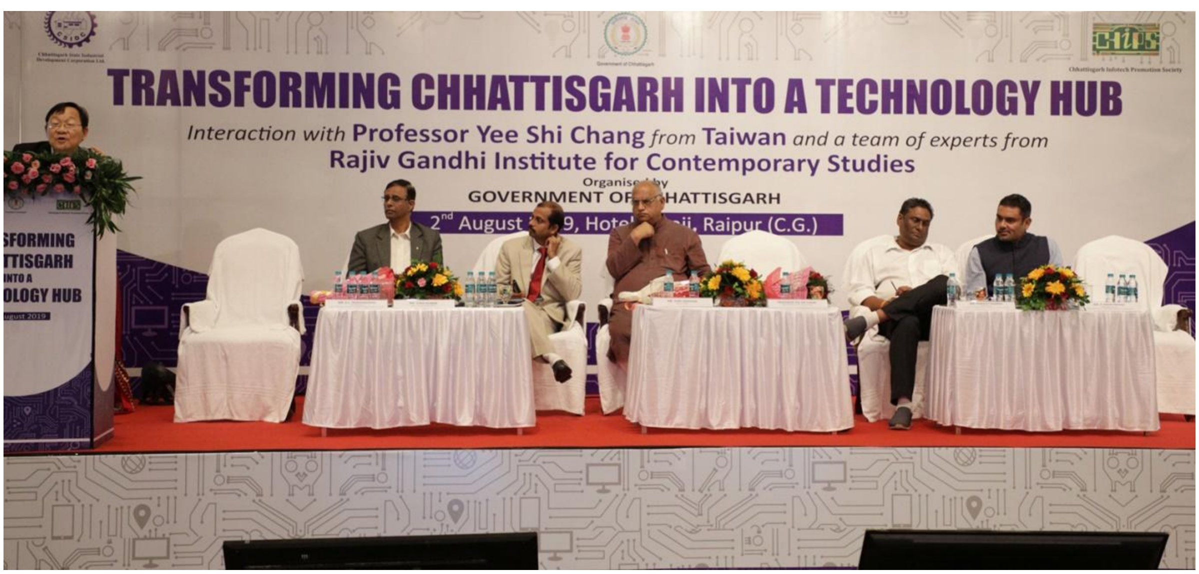
The cooperation in science and technology contains a wide range of fields such as agricultural and food science; new material for sustainable energy and storage devices; health care including functional genomics, drug development and biomedical devices; earth, atmosphere and ocean sciences including disaster management and digital technology for societal applications and cloud computing.

5.6. Education Cooperation

Over the past decade, over 200 Indian students have availed themselves of scholarships offered by the ROC (Taiwan) government. At present, there are 100,000 foreign students studying in Taiwan, of whom 1,310 students hail from India. Foreign students are encouraged to study in

Taiwan, and India is one of the countries whose students we actively pursue. In 2010, Foundation for International Cooperation in Higher Education of Taiwan signed an MOU with Association of Indian Universities, by which academic degrees and certificates recognized by one will be recognized by the other, allowing for greater research collaboration and exchanges by teachers and school administrators.

Currently, there are 7 Taiwan Education Centers (TEC) set up in various universities in India with 13 teachers from Taiwan teaching Mandarin Chinese. Over 4,000 Indian students have taken Chinese courses in India. The TECs in Indian also provide Chinese courses for senior Indian officials, tourism promoters and employees working for Taiwan enterprises in India.



6. Establishing an SiC Based High Tech Manufacturing Hub in Chhattisgarh

6.1. Chhattisgarh IT&ES Policy 2014

Chattisgarh, unveiled its vision for IT&ES in 2014, in line with the National Policy for Electronics (NPE) 2012. The vision for an "e"-nabled society for Social and Economic Development outlined the following key objectives.

- A strong, innovative, Information Technology support and incentive mechanism;
- State investors especially small and medium enterprises (SMEs), confidently using technology, access to robust infrastructure, trade online, seizing technological opportunities and increasing revenues in domestic and international markets by operating from the state;
- The digital infrastructure (both physical and regulatory) and the framework for cyber security and privacy necessary to support growth, innovation and excellence;
- Promoting a highly skilled digital workforce who create develop or support information technologies;
- Citizens with the capability and confidence to make the most of the digital age and benefiting from excellent digital services

Chattisgarh has made some progress with creation of Infrastructure (through Electronic Manufacturing Cluster (EMC), ITIR Park and E-governance support Infrastructure like Optical Fibre network, State wide Area network, etc.), investment into Human resources (through set up of Technology institutes like IIT, NIT, IIIT along with large scale Skilling and manpower mobilisation initiatives).

However, to enable active participation in the Electronics revolution, the state would need to ramp up its efforts towards establishment of a High value added Electronic manufacturing hub, that would enable generate large scale employment and propel the state towards economic prosperity.

6.2. Opportunities in High Value Added Electronics

Apart from factors critical to business development, namely, good governance, essential infrastructure coupled with a surplus of power, a stable labour environment and talent pool, the state is also the largest producer of Steel in India (Chattisgarh contributes 32.0 percent to India's Steel/Sponge iron production). Steel is one of the core raw material required to build a robust Electric Vehicles manufacturing sector. (Refer Box 1 below)

Box 1: The future of Steel in Electric Vehicles.[9]

The world is in the middle of an evolution of its mobility systems. Electric vehicles are more aesthetic, high-performing and efficient than ever. And thanks to government policies supporting greener transport, there is set to be a dramatic increase in the number of EVs on our roads over the next five years. In Europe, the number of EVs rocketed to more than a million in 2018, while China's car market continues to lead the way.

In recent years, steel has increasingly been favoured over Aluminium as the metal of choice in EV construction, largely because of its lower cost and superior strength. Materials like Advanced High Strength Steels are playing a vital role in lowering vehicle weight while still offering high passenger protection. EV manufacturer Tesla, for example, shifted to steel for its first mass market offering, the Model 3. Other manufacturers who have opted for steel in their vehicles include Nissan, for its Leaf model – the best-selling all-electric car world wide – and Volkswagen for the e-Golf.

Table 6 EV Market Potential in India (2026), Segment Wise. Source: Innovation Norway, NITI Aayog & Internal Estimates (on Average Prices).

2016-17 Revised Classification as per NITI Aayog		2016-17 (Domestic Sales)- SIAM Data	2016-17 (EV)-Estimates	2026 EV Projection (In Nos)	2026 Estimated Value (In B $)
2 Wheeler		17,589,511	22,000	10,620,000	9.1
3 Wheeler		511,658	50	675,000	1.2
LDV	Passenger Vehicles – Personal	2,132,709	2,000	17.9	17.9
	Passenger Vehicles - Commercial/Fleet	914,018		32.9	32.9
HDV	Commercial Vehicles – Passenger	98,126	20	5.6	5.6
	Buses*	170,000	0	33.0	33.0
Total		**21,416,022**	**24,070**	**15,892,000**	**99.7**

According to Innovation Norway in its India EV report (based on inputs by NITI Aayog), the transformative potential for EV's across segments in 2026, is estimated at 15 Million vehicles. This translates into an estimated value of $ 100 Billion. (Refer Table. 1 above). The $ 100 Billion opportunity in the EV space has led to many states creating a comprehensive Electric vehicles policy. Fourteen Indian States including Andhra Pradesh, Tamil Nadu, Karnataka, Punjab, and recently Delhi have announced their Policy.

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[9] https://stories.worldsteel.org/automotive/electric-charging-vehicles-future/

While EV shells are made of steel and other materials, the operational mechanism is in EVs entirely based on electronics capable of handling significant amounts of power, because of the need to carry current from the battery to the drive. This requires specialty semiconductors like Silicon Carbide (SiC), which can handle high power.

Thus to enable the state to become one of India's Electric Vehicle manufacturing hubs, it would be imperative for Chattisgarh to create an SiC manufacturing hub as well. This would not only cater to Electric Vehicles, but would also enable extension into multiple sunrise industries like Solar power, Data Centres, 5-G towers, Precision agriculture to name a few.

Table 7 below summarises the Top 4 opportunities for SiC in various applications. The market for these applications, is estimated to be around $ 700 Billion by 2030, with the devices market expected to contribute nearly $ 80 Billion,

Table 7 Market Estimates for Applications, Source: Research & Markets, NITI Aayog, Allied Market Research Solar Energy Market

Application	2020	2025	2030
Electric Vehicles	$ 5 Mn	$ 100 Bn	$ 300 Bn
Solar Power	$ 22 Mn	$ 100 Bn	$ 180 Bn
Data Centers	$ 4 Mn	$ 15 Bn	$ 40 Bn
Industrial Machinery	$ 85 Mn	$ 120 Bn	$ 200 Bn
Total	**$ 116 Mn**	**$ 335 Bn**	**$ 720 Bn**

6.3. Roadmap for Setting up an SiC based Manufacturing Hub in Chhattisgarh

The technology know how for Silicon Carbide (SiC) is currently limited to US, Japan, Germany, China and Taiwan. The Taiwan government has approached India for a technology transfer for the establishment of a SiC manufacturing hub through an Indo-Taiwan Joint Venture. This will also bypass the need to deal with the People's Republic of China, which is not appropriate under the current circumstances. Unlike the huge costs required for the setup of a conventional Fabrication facility, the SiC investments are comparatively smaller, and makes for a good business case for investment.

Our recommendations for establishing a SiC based Power Electronics Manufacturing Hub in Chhattisgarh, possibly at Naya Raipur, India's first smart city are summarised as follows:

a. In Phase 1, Invite 5 companies (Indo- Taiwan JV) to establish Link 1, i.e. System Design & Architecture focused on EV's (3 companies- Passenger, Personal LDV & Electric Bus) and Solar PV Inverter applications with SiC. *The estimated investments in Phase 1 to establish the JV* *companies would be $ 25 Million ($ 5 million would be the cost to establish up each company). These companies can immediately cater to the SiC System Design requirements of the existing EV and Solar companies in India.*

b. Identify potential Taiwanese partner to establish Link 2 i.e. the Foundry Fab/SiC Manufacturing facility in India. Potential foundries could be Episil and Vanguard, which are two of the leading SiC wafer manufacturing facilities in Taiwan. In Phase 1, we recommend that India will source the SiC wafers directly from Taiwan, whilst setting up its own SiC wafer facility in Phase 2. *The estimated investments required to set up a Fab Foundry for SiC manufacturing is $ 150 Million. Further expansion can be considered in Phase 3 to meet additional demand requirements.*

c. Packing & Assembly forming the Link 3, is a critical requirement in the SiC value chain and would require early investments in Phase -1. The packing facilities would also include an In-house Epoxy Plastic & Ceramic manufacturing facility required for the final assembly of the SiC modules. *The Investments into establishing EV and Solar PV modules would be $ 100 Million.*

d. The Electronic Power Systems required to drive the modules would be assembled in Link 4. This would include setting up of a manufacturing facility for Permanent Magnet (PM) Direct Drive Motors, as well as a facility for Lithium Polymer (Li-Po) Giant batteries. *The investment to set up this facility would be $ 100 Million. Subsequent expansion can be done in Phase 2 for another $60 Million to ramp up production in anticipation of additional demand.*

e. Subsequent investments for increasing scope of applications & scale of production can be planned in Phase 2 & 3. The additional investments would be linked to the capacity being expanded, as well as the scope of applications.

f. The rationale for semiconductor investment is strengthened by India's significant semiconductor GDP multiplier (Refer. Fig 8). The GDP multiplier for 1$ of technology investment is expected to be 21-23 X)[10]

Establishment of the SiC value chain for manufacturing would alone lead to creation of 1 Million jobs (Direct and Indirect employment). Another key highlight of the semiconductor industry, is that globally it has helped to bridge the gender divide, by ensuring a healthy ratio of women candidates, with close to 20% of the workforce consisting of women.

As next steps, (subject to COVID travel norms being eased), we would recommend a high level delegation from Chattisgarh to visit Taiwan to understand the SiC ecosystem prevalent, which would include visits to Foundry / Fabrication facilities as well as Electric Vehicles Design and development facilities.

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[10] GDP Multiplier for $1 investment into Semiconductors, Source Ernest & Young

7. Conclusion

Silicon Carbide (SiC), the Super-Hero cousin of Silicon (Si) is expected to revolutionise the "Next Generation Power Device". Many SiC power devices have emerged as superior alternative in the power switch technology, especially in harsh environments with high temperature or high electric field. SiC has entered the growth phase and is expected to grow further in the coming years.). The end use case application in India is expected to be $ 800 Billion by 2030, with 65% of the demand being driven by Electric Vehicles (EV) and Solar PV Inverter applications. The SiC devices market for India is expected to be worth $300 Billion by 2030.

Increasing penetration of SiC in semiconductor industry provides a perfect opportunity to become a major producer of SiC based power electronic devices. The Indian semiconductor industry took off about three decades ago, but India remains a negligible player in the global semiconductor industry with a meagre presence in Link 1 i.e. System Design and Architecture.

This paper strongly recommends to invest into the SiC manufacturing across three Phases. The technology transfer would be through Taiwan, which has been at the forefront of the SiC revolution. The initial investments to set up the SiC value chain in Phase 1 is estimated at $ 375 Million. This investment would cater to the immediate demand in the EV and Solar PV Inverter applications. Subsequent investments for expansion can be planned basis an assessment of the growth and demand in these sectors, and also extension into other applications.

Apart from the economic benefits of catering to a captive domestic demand of $800 Billion, India could consider the large export potential for countries like China, Indonesia and the Africa continent. Further, the establishment of SiC powered Power Electronic Devices ecosystem would build on the semiconductor design industry and provide new avenues for employment generation. Establishment of the SiC value chain for manufacturing would alone lead to creation of direct and Indirect employment. Another key highlight of the semiconductor industry, is that globally it has helped to bridge the gender divide, with close to 20% of the workforce consisting of women. It is environmentally friendly and low on land requirement. This could be the breakthrough to build a high-tech manufacturing base for Chhattisgarh

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