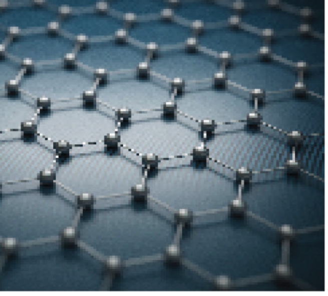
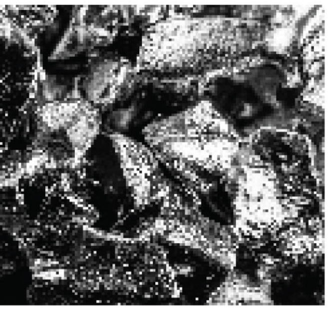
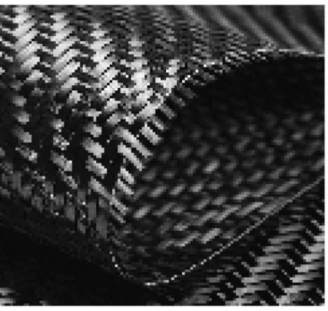
Confederation of Indian Industry







Thought Leadership Report
on

ADVANCED MATERIALS

"Redefining Manufacturing Excellence For Global Leadership "

GRAPHENE

TITANIUM AND ITS ALLOYS

CERAMICS

RARE EARTHS

BIOMATERIALS AND IMPLANTS

COMPOSITES

RECYCLING MATERIALS

April 2023

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Foreword

Mr Vipin Sondhi
Chairman, CII National Mission on Technology, Innovation and Research

India is on a Technology and Innovation driven Mission during the ongoing Amrit Kaal. For this mission to come true, technological leadership will have to be a critical imperative.

One of the key components of technological leadership is Advanced Materials. Advanced Materials are at the cutting-edge of the world's technological frontiers, as they are beginning to play a vital role in every aspect of our lives. Advanced Materials have therefore the potential to shape the future of India and play a massive role in the transition to a low carbon, knowledge-based economy.

Under the aegis of CII National Mission on Technology, Innovation and Research, CII has prepared a Thought Leadership Report on Advanced Materials which provides a detailed overview on specific Advanced Materials including Graphene, Titanium, Biomaterials, Recycling Materials, Composite Materials, Ceramics and Rare Earth Elements.

I am sure this report will serve as a good reference point for taking forward the mission on Advanced Materials. A collaborative approach by industry, academia and govt (labs) would help bring out solutions for shaping tomorrow's future with safer, cheaper, faster, technologically Advanced Materials that meet the requirements of a low carbon, knowledge based, circular economy. My sincere thanks to the members who have contributed towards the development of this report on Advanced Materials.

Dr Debashish Bhattacharjee
Vice President, Technology & New Materials Business, Tata Steel Limited
Chairman, CII Task Force on Advanced Materials

Materials science is one of the most influential innovation moats for sustainable and resilient socio-economic growth. Advanced Materials have applications across myriad sectors – from agriculture to transportation & from defence to space. Therefore, materials science should be an integral part of India's innovation strategy to fuel sectoral advancement that can drive the next era of economic growth.

With this in view and under the aegis of CII National Mission on Technology, Innovation and Research, a thought leadership report has been prepared by the CII National Task Force on Advanced Materials comprising of an elite group of experts. The report focuses on seven Advanced materials: Titanium, Biomaterials, Materials from Urban Mining, Composites, Rare Earths Elements, Advanced Ceramics and Graphene.

The report highlights the background, strategic importance of the material, Indian scenario, gap areas, technology frontiers and, role of the stakeholders such as, Government, Academia, Industry and Research Institutes. The report concludes with short, medium, and long recommendations for each of the mentioned material.

Sustainable progress happens when technology meets business and fulfils the techno-business demands. I am sure this report will serve as a good reference point for taking Advanced Materials mission forward, thereby giving a boost to the growth journey of our nation.

Acknowledgement

Under the leadership of Mr Vipin Sondhi, Chairman CII National Mission on Technology, Innovation and Research and Mr Alok Nanda, Co-Chairman, CII National Mission on Technology, Innovation and Research the National Technology Mission, has been spearheading with an aim to make Technology as a movement across the nation. Advanced Materials is one of the key focus technology frontier under this Mission.

We would like to acknowledge the leadership and support of Dr. Debashish Bhattacharjee, Vice President, Technology & New Materials Business, Tata Steel and Lead –CII Advanced Materials Mission for guiding and leading this initiative.

The chapters in the report are drafted by the eminent subject matter expects, which provided the framework that formed the backbone for the analysis, subsequent findings, and recommendations in this report.

We would like to acknowledge and express gratitude to the following experts for their contributions in the respective chapters:

- Prof. Amol Gokhale (Proposed), Professor, Department of Mechanical Engineering at Indian Institute of Technology Bombay
- Dr Suman Mishra, FNASc Director, CSIR-Central Glass and Ceramic Research Institute
- Dr R N Patra, Former CMD, Indian Rare Earths Limited (IREL)
- Prof. Bikramjit Basu, Professor, Materials Research Center, Indian Institute of Science, Bangalore
- Dr Bankim Chandra Ray, Professor, Department of Metallurgical and Materials Engineering at National Institute of Technology, Rourkela
- Dr U. Kamachi Mudali, Vice Chancellor at VIT Bhopal University, Former Chief Executive & Chairman, Heavy Water Board

From CII, the efforts were led by Shri S Raghupathy- Principal Adviser, Dr Ashish Mohan- Executive Director - Technology, R&D, Innovation and Design, Ms Namita Bahl- Director, and Ms Tiksha Madan- Executive Officer.

Lastly, to all the subgroup members and respondents for their valuable inputs in the report.

Executive Summary

Advanced materials are new materials with enhanced properties that are intentionally designed for superior performance. Advanced Materials have the power to drive technological innovation and are critical as they have applications across all the technology verticals from defence to space. Demand for clean and efficient energy, sustainable mobility, cutting-edge healthcare, urban infrastructure, potable water, and other amenities is rising exponentially, hence Advanced Materials are critical for national importance. These are economic pillars that are integral for the growth of India, hence Investing in materials innovation is investing in India's future.

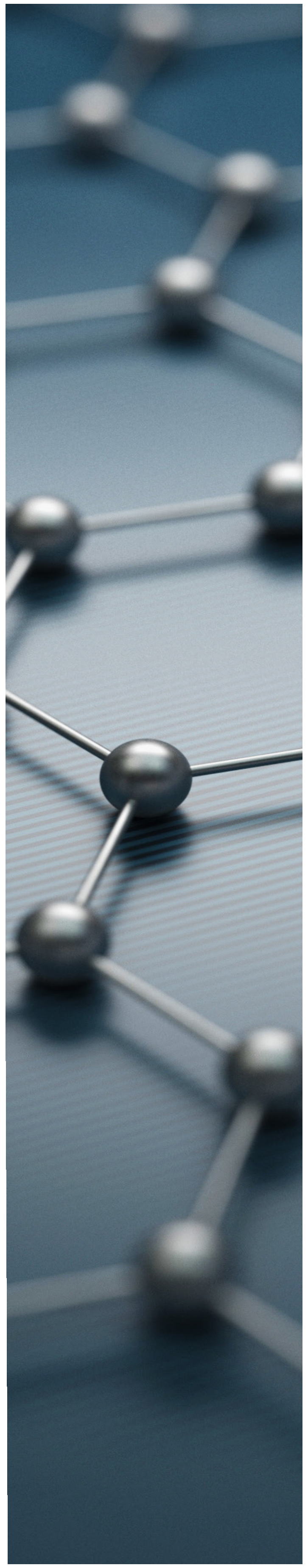
With this as a background, the Confederation of Indian Industry (CII) is on a mission to launch Advanced Materials as a movement across the nation that envisages to enable India take strategic initiatives towards technology leadership.

This report is a part of Advanced Materials initiative taken by the CII. The focus sectors of the aforesaid report include Graphene, Titanium, Biomaterials, Recycling Materials, Composite Materials, Ceramics and Rare Earth Elements.

The reports highlight the background, strategic importance of the material, Indian scenario, gap areas, technology frontiers, role of the stakeholders such as, Government, Academia, Industry and Research Institutes and Short, medium, and long Recommendations.

This report has been developed by an intense pool of technology experts, policy makers, eminent academicians, and industry stalwarts. Each chapter has been individual prepared by dedicated set of experts, involved in series of meetings and discussions.

This report helps to identify a road map for Advanced Materials and their importance/ need for India.



CHAPTER 1:

GRAPHENE

1.1 Material and its Background

In 2004, Andre Geim and Konstantin Novoselov successfully isolated a stable single atomic layer of graphite at the University of Manchester. They conducted a series of experiments and showed remarkable electrical and thermal properties. This was a new epoch in material science, It was the first two dimensional nano materials that was discovered. In the experiments that followed this discovery by various groups around the world it demonstrated tremendous mechanical strength, excellent electrical and optical properties as described in the Figure 1.1.1. In 2010, Geim and Novoselov were awarded the Nobel prize in physics for this breakthrough work.
With all the properties that has been reported by researchers around the world, scientists now believe that graphene can bring disruptive technologies in future

1.1.1: Properties of grap Figurehene and its derivatives.

1. Pristine Graphene can be produced only in small quantities and mostly in research labs. However, its large-scale production presents unsurmountable challenges.

2. In the recent years large scale production of Graphene via. chemical method, such as Hummer's method and thermal exfoliation methods have been used.

3. The graphene produced, come in several variants that may be classified into thwwree broad categories, namely as:

a) Graphene oxide
b) Reduced Graphene oxide
c) Functionalized Graphene

These Graphene variants have been produced around the world for specific target applications. Graphene oxide contains functional groups that can be exploited to interact with other materials for applications in coatings, composites, water filtration, and sensors etc.
However, its reduced form which had good electrical properties can be used in battery applications, electrochemical sensors, etc.
Graphene can be grown in the form of films but only on few selected metals such as copper and nickel. To develop applications using graphene films, transfer process has been developed which allow transfer of graphene films from metal substrates to variety of substrates such as Silicon, PET, glass etc. Efforts have been put to develop a roll-to-roll growth and transfer process of graphene films. Such films can find applications in flexible display and optoelectronics.

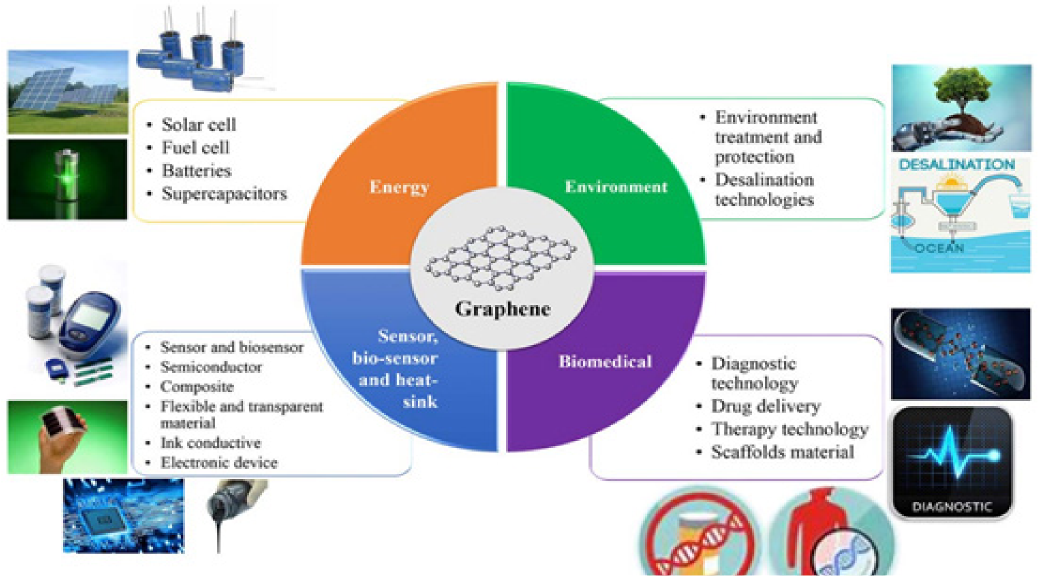


Figure 1.1.2: Potential Graphene Applications

1.2 Strategical Importance of Material for India

For India to truly emerge as a global technological powerhouse, investment in R&D with focus on emerging material and technology is need of the day. Access to deep material technologies will enable India to propel and develop world class products for global human, social and Industrial good. IP at material level will help define countries potential to lead multiple product play in global economy.

a) Graphene is known as wonder material of 21st century because of its potential to create value in almost all streams of technology varying from polymers, coating, energy, structural, textile biomedical etc.

b) Graphene has enormous potential to enhance performance by doping or replace existing materials because of its range of properties such as strength, conductivity, im-permeability, bio compatibility and optical properties.

c) India in past has missed the bus with regards to Solar revolution. One among many other reasons is access to deep material technology, say Polysilicon manufacturing competence. Lack of technology to convert abundance of sand as potential raw material into Polysilicon competence could be a great learning. Graphene technology with sufficient access to Graphite and other potential raw material within India provides India and opportunity to take pole position.

d) Successful synthesis of Graphene and developing graphene enriched products would have direct contribution to India's technology leadership position and Innovative index. The new era of "Sustainable future" would derive many values from Graphene, its variants and its use in developing cutting edge and affordable products for greener energy, health care, mobility, electronics, sustainable packaging, EV, energy storage, Water, infrastructure, Aerospace and Defence to name a few. A leadership position in graphene and its application would create a true potential opportunity for India's Research and Development competency to be harnessed by global economy.

1.2.1 India being one of the fastest growing economies, graphene has the potential to play in a large part of the future technologies.

Following are few potential areas of significance:

a) Research has found that the graphene is promising material for fast charging battery anode. Looking at the future of electrical vehicle (EV), and more electronic gadgets, it is important to have batteries and energy storage devices produced in India.

b) Use of graphene in water filter applications, with not enough groundwater or potable water, graphene can play a major role in removing unwanted minerals and through filtration technology with in-house graphene production in bulk, reduce the cost of filter membranes and opportunity to say desalination of sea water thereby providing water security.

c) India is inviting global player to setup chip making semiconductor foundry. Integration of graphene into conventional silicon-based fabrication offers a promising future, allowing combination of high-performance graphene devices with established CMOS readout circuitry, with production costs as low as conventional silicon technology. Graphene's conductive properties will play a role in wearable and flexible electronics, RF IDs antenna and biosensors.

d) India has huge presence in polymer and packaging manufacturing through organized and unorganized sectors. Value added Graphene polymer composites strength and functional properties such as thermal conductivity and anti-static properties. Rubber and paints are other sector wherein graphene can play significantly.

e) Graphite is abundantly available naturally in India. Graphite can be converted into graphene via top-down exfoliation processes such as liquid phase, electrochemical, thermal, and chemical exfoliation. Last decade has seen lot of focus on development of scalable exfoliation processes. Graphene is important material globally because of its application potential. With focused graphene production using natural reserve graphite, and its synthesis competence India can become global source for supply of graphene and its variants.

1.3 Global Value Chain

Till 2017 China was the leading producer of Graphene oxide in the world with a capacity of 710 tonnes per year. The total capacity of Europe and USA was around 10% of China's total capacity. While the graphene nano-flakes production was highest, with China having a production capacity of 1400 tonnes per year. Europe and US combined produced around half that figure. This scenario has changed at the beginning of this decade with US and Canada taking leading position.

Around the world graphene is produced by various routes. More than 80% of applications have used graphene oxide (GO), reduced graphene oxide (rGO) produced by chemical methods and graphene nano-platelets (GNP) produced by thermal, liquid phase exfoliation and other methods.

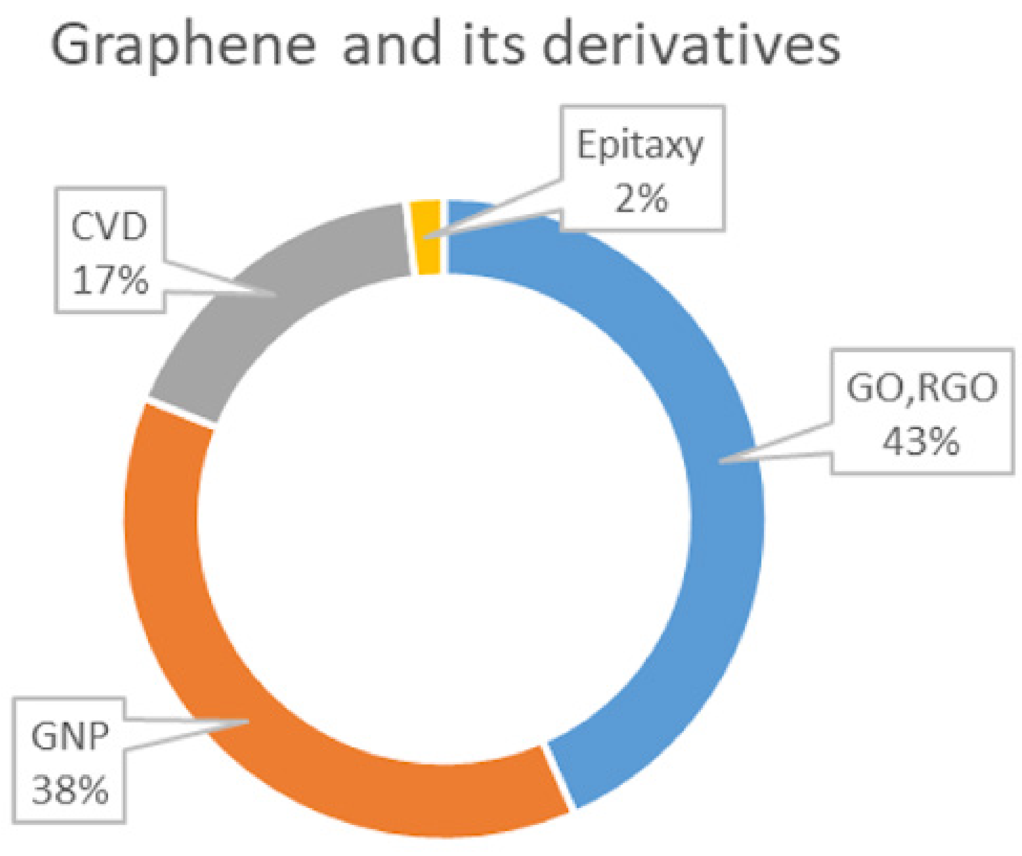


Figure 1.3.1: Graphene and its derivatives production trend globally (based on number of companies).Indian has one among top 10 Graphene producing industry player early with capacity exceeding 100 tonnes per year as of 2021. Please find below Key producers globally and their volumes:

Supplier Name	Country	Tonnes per year	Application Focus
NanoXplore	Canada	4000	Composite & Energy
Elcora Resources	Canada	2500	Energy
SuperC Technology	China	1000	Energy, Coating, Thermal, Composite
Sixth Element	China	1000	Composite, Coating, Energy, Ink, Adhesive
Global Graphene Group	USA	300	Thermal, Ink, EMI, Coating
Graphene XT	Italy	300	Lubricant, Coating, Composite, Membrane
Ningbo Morsh	China	300	Composite, Energy, Ink
Gnanomat	Spain	200	Ceramic, Energy
Tata Steel	**India**	**100**	Composite, Coating, Fabric, Energy
First Graphene	Australia	100	Composite, Concrete, Energy
Avanzare	Spain	100	Thermal, Ink, Flame retardant, Composite
Carbon Solutions	USA	100	Commercial sale
Gerdau Graphene	Brazil	100	Concrete, Composite, Lubricants, Coatings, Sensor
Graphenano	Spain	100	Concrete, Medical, Composites, Sensor, Energy
Leadernano Tech	China	100	Coating, Energy, Composite, Sensor, Membrane
Talga Resources	Australia	100	Energy
Cabot	USA	80	Composites, Battery, Ink
Chengdu Organic Chemicals	China	80	Foam, Composite
Beijing Qingdajiguang Technology	China	50	Ink, sensors, Hydrogen storage, catalysis
Directa Plus	Italy	30	Textile, Tyres, composites, Membrane, oil spill, ink
DDH Advanced Materials	USA	30	Ink, Energy, Hydrogen Storage
Haydale	UK	30	Ink, Sensor, Ceramic, Energy
Garmor Inc.	USA	20	Membrane
2D Materials	Singapore	12	Textile, Energy, Lubricants, Ceramics, cement
Suzhou Gaotong Graphene-Tech	China	12	Thermal, Coating
Abalonyx	Norway	10	Sale
Applied Graphene Materials	UK	10	Coating, Composite, Lubricant, Energy

Figure 1.3.2: Key Producer and their volume (based on our own research)

Key market segments:
a) Graphene is not one material, but a range of material depending on how it is functionalized. A new variant can be developed to complement a specific application.

b) Two vectors for Graphene would define countries prominence and its ability to deliver breakthrough innovative products. The first is – Graphene material play with different variant and second is developing applications using the different graphene material delivering range of graphene value added product.

Graphene and its derivative can be widely used as an additive to polymer, rubber rubber and paint industry globally. Graphene has also seen traction for battery anode applications such silicon batteries, additive to graphite anode etc.

d) Single layer graphene dispersion is most suited for R&D activities and the art to functionalize graphene offers Industry to take lead in developing products for global good.

e) Graphene applications research so far has been focused on polymer composite, coating, energy, structural applications because of process simplicity for adaptation of graphene technology. However, effort has been put to find success in niche applications with focus on market disruption such as touch screens, chip interconnects and quantum electronics. Please find below list of graphene application focus areas.

Figure 1.3.3: Application Focus ranking based on research activities in listed domain

Market Size:
Current market size is around 1350 million USD based on listed companies' data. The world graphene market is expected to grow at 31% CAGR to USD 900 million in 2030 [Global Market Insights].

1.4 Indian Scenario

The Indian scenario in graphene production and its application is still in emerging stage. Most of the players are start-ups with a few major players. As compared to China's, which is one of the largest contributors to graphene productions in the world, we still lack the ecosystem required for innovation and collaboration across the industry. There is also less awareness about the possible advance technology that could be possible by using graphene.
Global graphene market is expanding and is adapting Graphene technologies to improving product performance for better consumer experiences.
For example, Samsung is focusing on graphene-based touch screen development for flexible display. Huawei has used graphene to develop long-lifespan graphene-assisted Li-ion battery to withstand high temperatures. Semiconductor industry is looking into graphene and other 2D material as means for continuation of Moore's Law.

However, steps are underway to meet and exceed global play with Government committing resources and giving the opportunity to Industry and academia to collaborate to retire R&D risk quickly, help commercialize technology with scale. One such initiate is India Innovation Centre for Graphene established by MEITY, Govt of India in collaboration with C-MET, Digital University Kerala and Tata Steel as Industrial partner. Centre aim to build graphene technologies, create human talent, engage and energise start-ups and Industry with global academic and Industrial alliance. Path-breaking initiative from government specially giving Industry to lead leveraging their operational excellence competence. Academia and R&D competence being augment with Industrial anchor is one of unique India is positioning to address eco-system ask.

India is expected to have a digital economy of USD 1 trillion by 2025, and India's electronics system design and manufacturing (ESDM) sector is expected to generate over USD 100 billion in economic value by 2025. Electrical and electronics production in India is expected to increase rapidly due to government initiatives with policies, such as Make in India, National Policy of Electronics, lozwering import dependence, energizing exports, and manufacturing, like the "Make in India" program to make the country self-reliant. Graphene conducting ink technology can contribute for growth of digital economy.

1.5 India Value Chain v/s Global Value Chain

India being home of the world's second largest population, poses the unique position in terms of a large market with continuously increasing demand of the advanced technologies, and huge manpower to be employed for such technological developments. Like any global graphene value chain, large number of Indian universities and research institutions are engaged and are best suited for rigorous R&D activities furthering fundamental research on standardisation of different graphene specifications.

The emerging value of graphene technology offers industry leaders from across the sectors to come forward, collaborate and encourage R&D for a purpose then leading to large-scale production of graphene and specific applications. This approach would assist India to rapidly get out of boot-strap approach of graphene's and potential scalable applications. Large scale commercial applications are stuck as it requires scaled-up consistent graphene production, and on other hand scaled-up graphene production is stuck as scalable applications are yet to be identified or popularised for use by large population as a market.

The above chicken-egg dilemma is prevalent equally across the globe; however, sense of awareness is developing globally to enable the application of the graphene, the wonder material. Today, India rather has certain advantages compared to the other global leaders, in terms of available resources, technical competence, production capacities and to top it all market requirements.
India, having a matured academic and industrial calibre if set into full motion, should be able to become the leader of graphene technologies, providing answers to the rest of the world, on what strategy should be applied for this technology development.

1.6 Gap Areas and Recommendations to Fill Gaps

- **Technology:** Graphene, unlike other materials, heavily rely on intermediate material developments and processing towards a final specific application. **For example,** the type of graphene required for battery applications can be very different from the graphene used for coating technologies. Also, this is a highly process dependent technology, and performance can be heavily dependent on the way graphene has been processed. This uniqueness of the graphene imposes challenges in terms of standardization of graphene and its applications. At this point, India has great opportunity to standardise graphene and setting up steady state applications of graphene. Government along with industries need to identify products relevant to India with graphene intervention. Industry should come forward to define the problem statement with focused mandate for graphene-based technology development. Industry can launch technology oriented project with specific target to optimized graphene doping and scalable process for graphene addition to different polymer systems. sfasfaddfafafddddfdfdfdfdfdfddfd EV driven automobile industry should sponsor technology projects with mandate to make part of vehicle with ultralight using graphene and its variant. Government should join hand with industry to jointly fund such programs. We need to bring structure in graphene-based research program going on in research labs and IITs in India. Industry should lead competency gap identification, Government should fund technology development project in graphene applications across widely adoptable areas such as polymer composite, energy storage and academia should bridge intellect gap in making Graphene technology a reality.

- **Government Support:** Push for applied research and indigenous technology. Developing innovation and research ecosystem, where academia and industry can both come together to solve problems. There should be an understanding of where the market is moving and what are the needs. Government should support funding and industry should lead deployment of program with agility. IP should be effectively monetized.
- **Collaboration:** Industry and academia partnerships. Fast innovation and application development research. India Innovation Centre of Graphene is one such example which has potential to bridge this gap. For any specific technology development different work packages can be developed which can be further taken up by R&D centres individually.
- **Infrastructure:** We have sufficient lab and R&D infrastructure in India to support graphene technology development. To develop skilled manpower for mass production of graphene, university should launch specific master program for nano material manufacturing with focus on graphene. Diploma course for one year can also be considered.
- **Supply Chain**: Large scale graphene flakes can be produced through exfoliation of graphite using processes such as liquid phase exfoliation, electrochemical exfoliation and chemical exfoliations. India comes at seventh position in terms of global graphite reserves. These graphite reserves can be converted to graphene at affordable cost with development of graphite beneficiation and exfoliation technology.

1.7 Role of the Stakeholders such as, Government, Academia, Industry and Research Institutes

Formation of an Apex dedicated governing body with members from Government, Academia, Industry and Research Institutes, such as a Graphene-council, may help significantly to speed up this process. Such council can initiate the process of identifying all possible specific application segments, such as potential usage of graphene in energy storage & harvesting applications, in electronics applications etc., with main fucus to standardisation requirements of graphene. Thereafter, setting up academia-industry collaboration to establish roadmaps to achieve those targets, and initiation of futuristic projects targeting specific application domains.
Government should be able to launch program under skill India initiate to support graphene-based industries. Research institute will provide work force to carry out the technology led research projects. For graphene quality check industry should make standards. Government should develop process for certification of graphene and graphene enriched products.

1.8 Recommendation and Conclusion

Industry to lead the technology way, government should provide anchor and research funding, academia the intellect capital and engaging the Industrial and start-up ecosystem would put India's graphene revolution in motion.
In the midterm, R&D project can be executed with focus on scalable technology development under supervision of partnering industries.
Government can provide soft loan to MSME and start-ups to setup of manufacturing plant for production of graphene and graphene-based products. Start-up focused special call can be open for graphene based on product development.

Government along with leading industries should collaboratively work together to get the best and develop products using graphene technologies. Graphene the most promising material for next generation technologies has yet to get its place in India. Thus, it is essential to put our right efforts to develop inhouse graphene applications deliver breakthrough products at an affordable cost for local and export market. Further creating jobs in India.

Graphene a wonder material has unique properties and thus can be used in wide range of applications ranging from electronics industry to composite and so on. Last decade has observed that gradual improvement in graphene production globally with production cost going down. In terms of applications, value addition through graphene has impacted polymer composite, coating, cements, sensors, bio applications etc. The Global Graphene Market is expected to grow by 811.40 million dollars by 2023, with a compound annual growth rate of 43.0 percent between 2016 and 2023. Considering expert opinions and reports, the advantages of investing in the graphene technology are clear.
The graphene industry in India being in its initial stages very little work is done in terms of regulations and standards. Impetus must be given by both industry and government with supporting policies for funded research and commercialization.

1.9 Chapter Contributors

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CHAPTER 2:

TITANIUM AND ITS ALLOYS

2.1 Material and its Background

Titanium alloys have a relatively low density, high corrosion resistance, ability to develop high strength and good creep resistance up to about 550 °c. As a result, they are widely used in air frames and aeroengines. Their usage in other sectors is limited to biomedical implants, chemical processing equipment, sports goods and to a small extent, armour. A large proportion of Ti alloys are used as forgings, plates, sheets, tubes and, to a small extent, castings [Lutjering 2007]. The initial applications of titanium alloys in aerospace were in the compressor section of the aero-engine, where their high temperature capability was primarily the reason for their selection. However, the introduction of Ti-alloys in the air frame of Boeing 787 saw a major shift in the material distribution in that application (Fig 2.1.1). They replaced aluminium alloys in the air frame, in spite of their higher density. This was possibly because Boeing had decided to use CFRP (Carbon Fiber Reinforced Polymers) in the air frames due to their higher strength to weight ratio and the fact that aluminium is not galvanically compatible with CFRPs [Hakansson 2016].

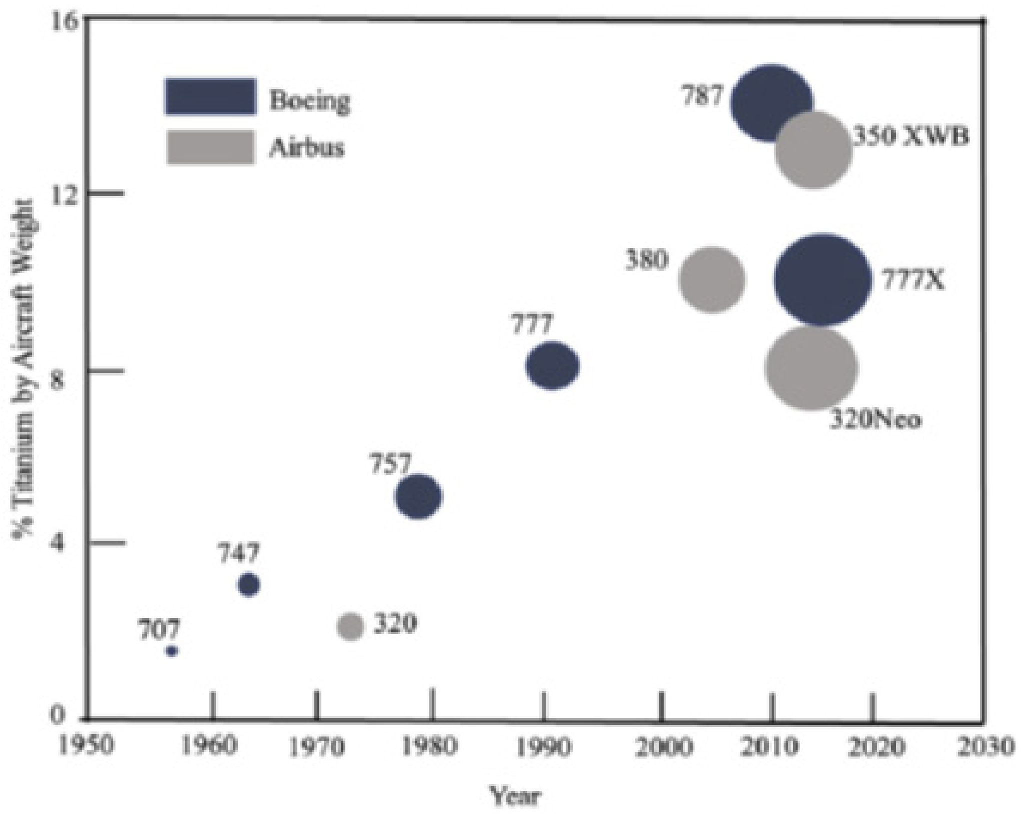

Fig. 2.1.1: Usage of Ti-alloys in commercial airplanes [Sankaran 2017]

Parts of the landing gear of Boeing 777 and 787 are now made of Ti-alloys, which were earlier made of high strength steels, resulting in weight saving [Lutjering 2007]. Table 1 shows the gradual increase in the titanium content used in the air frames of various Boeing and Airbus passenger aircraft.
Future higher supersonic aircraft such as the Advanced Medium Combat Aircraft (AMCA) will perhaps see increased usage of titanium sheet components in near-engine locations due to service temperatures expected to be beyond the capability of currently used Al-alloys.
The other application where titanium could partially replace nickel is the aeroengine, where titanium aluminide intermetallic alloys could replace Ni base superalloys for High Pressure Compressor (HPC) blades and Low-Pressure Turbine (LPT) Blades [Lutjering 2007]. Some of these applications have already been realized in GE's recent engines [Bewlay 2016].

Materials Distribution (wt%)							
	Boeing [5]					Airbus [6,7]	
Material	747	757	767	777	787	A380	A350
Aluminum	81	78	80	70	20	61	19
Titanium	4	6	2	7	15	10 (Ti and steel)	14
Steel	13	12	14	11	10		6
Composites	1	3	3	11	50	22	53
Other	1	1	1	1	5	7	8

Fig. 2.1.1: Usage of Ti-alloys in commercial airplanes [Sankaran 2017]

2.2 Strategical Importance of Material for India

India is on a path to be a global player in defence and aerospace. The Advanced Medium Combat Aircraft is in the design review stage and will consume reasonable quantities of Ti alloys. Tata Airbus project will make military transport aircraft in India. Similarly, the space program uses Ti alloys in some of the launch vehicles. The medical materials industry, though small at present, is likely to grow. This is why Ti is a strategically important material for India. There are only a handful of companies which produce Ti and its alloys in the world and, hence, their sources are limited and vulnerable to supply disruptions.

2.3 Global Value Chain

a. Titanium bearing feed stocks such as chlorinable titanium slag, synthetic rutile and upgraded slag which contain higher than 85% TiO_2 are chlorinated at around 800°c by using chlorine gas in the presence of calcined petroleum coke to produce titanium tetrachloride which is liquid at room temperature. In Japan and USA production of titanium tetrachloride is carried out using a fluidized bed reactor, whereas in Russia, Ukraine, Kazakhstan and China, molten salt chlorinators are used for above purpose. The Japanese producers of titanium sponge adopted fluidized bed chlorination in place of fixed bed chlorination of titanium slag/rutile on account of enhanced production economy and ease of operation. The impurities in the titanium bearing feed stock form low boiling metal chlorides such as vanadium chloride, silicon chloride, ferric chloride and aluminium chloride as well as the high boiling metal chlorides such as calcium chloride, magnesium chloride and sodium chloride.
b. The titanium tetrachloride leaves the chlorinator in gaseous form at the reaction temperature containing the low boiling metal chlorides along with gases such as carbon monoxide and carbon dioxide. Some quantities of fine particles of titanium bearing feed stocks and petroleum coke etc are also entrained along with the titanium chloride vapour coming out of the reactor. The high boiling chlorides remain inside the chlorinator and require periodic flushing for ensuring smooth operation of the chlorinator. The titanium chloride is cooled, condensed and made free from the insoluble entrained fine particles by using suitable filters. The titanium chloride liquid is refined to its desired purity by further subjecting it to fractional distillation to remove all the low boiling chloride impurities.

The pure titanium tetrachloride is processed either by Hunter or Kroll Process to produce titanium sponge. The titanium sponge producers in USA and Japan have been using titanium bearing feed stocks containing >95% TiO_2 such as natural rutile, upgraded slag, synthetic rutile till 2010 whereas in China, Russia and Kazakhstan titanium slag containing comparatively lower percentage of TiO_2 (85 – 89%) is used as a feed stock. After 2010, due to economic reasons, the USA and Japanese producers have been increasingly replacing high TiO_2 containing feed stock with comparatively low TiO_2 containing feed stock such as chlorinable titanium slag containing 85 – 89% TiO_2. Among the two processes to produce Ti sponge, the Kroll's process will be described due to its relevance to India.

- **Kroll Process for titanium sponge:**

1. United States Bureau of Mines started producing titanium sponge in 15lb batches in the year 1944 after carrying out various modifications to the process developed by William Justin Kroll. Titanium sponge is produced by reducing titanium tetrachloride with magnesium metal at 9000°C. Though the process was initially developed by using calcium as a reductant in 1932, subsequently it was replaced by magnesium and even sodium. Titanium sponge production by magnesium reduction of titanium tetrachloride found commercial acceptance and by 1948 DuPont started operating a 100lb/day Ti sponge plant and sold the titanium sponge at the rate of USD 11/kg. The reductant magnesium not being soluble in chloride salts of titanium and the end product magnesium chloride about 30% excess magnesium above the stoichiometric requirement is used in the reactor and needs to be removed along with the reaction product magnesium chloride from the titanium sponge after completion of the reduction reaction.
2. In those days, magnesium reduction of titanium tetrachloride was carried out in separate reactors and the titanium sponge was transferred to another vessel after cooling the reacted mass for vacuum distillation of excess magnesium and magnesium chloride.
3. In 1956 Dupoint patented the technology of combined process in which the reduction reaction for producing titanium sponge and vacuum distillation of unreacted magnesium along with magnesium chloride was carried out in the same vessel. This not only eliminated the additional time taken for transferring the reacted mass to another vessel but also resulted in energy saving by avoiding the cycle of cooling and heating the reacted mass. This process had number of engineering problems which were subsequently addressed by Toho Titanium of Japan, who first adopted the process for commercial production of titanium sponge in 1978.
4. A comparison of energy consumption along with that for magnesium and chlorine for making titanium sponge by the combined process vis-à-vis the earlier process is presented in Annexure 8. The above-mentioned combined process used a single furnace, whereas in USSR the titanium sponge plants were using two reactors mounted one above the other with an isolation valve having two separate furnaces, one for carrying out the reduction reaction and the other for vacuum distillation. Combined process resulted in 30% saving in electrical power shorter cycle time and produced titanium sponge of high purity. Based on combined process, Japanese titanium sponge producers have developed technology to produce titanium sponge in batch size of 13 tons per batch resulting in enhanced production economy and higher yield of high pure titanium sponge for aerospace usage.
5. It is interesting to note that today titanium sponge is made in plants based on combined process of much higher capacities exceedingly more than 500 times those in 1948 using Kroll Process and is priced USD 18-20/kg. At the end of 2010, eighteen plants located in six countries of the world viz. Russia, Ukraine, Kazhakhstan, China, Japan, and USA had 2,38,000 tpa titanium sponge production installed capacity based on Kroll Process and the global production of titanium sponge was reported to be 1,32,000 ton in 2010. Annexure- 9. gives country-wise list of the major titanium sponge producing plants.
6. China has more than 1/3rd of worlds titanium sponge production capacity as eight out of eighteen plants producing titanium sponge in the world are located in China contributing more than 40% of global titanium sponge production.

- **Titanium powder**

In the early part of 1960, Titanium powder was produced by reducing fine pure titanium dioxide with calcium hydride and leaching out the reaction product calcium oxide from the titanium metal powder. A large plant was operated in the erstwhile USSR to produce very pure chloride free titanium powder. After dissolution of USSR the operation was suspended due to lack of market economics of calcium as a reductant is comparatively much more expensive than magnesium used in Kroll process.

Polema JSC, Russia currently produces about 3000 ton per annum of titanium powder based on above process. The titanium powder particles have irregular form and extended particle surfaces. Annexure-10 gives the characteristics of these titanium metal powders. Current global production of titanium metal powder is estimated to be not more than 10000 ton per annum and no reliable data is available for its production. Most production of titanium powder takes place in Russia, Ukraine and Japan. Russia and Ukraine have titanium powder production capacity of 2000 tpa and export of titanium powder from Japan average around 3000 tpa.

China also has titanium powder production unit of 1000 tpa based on technology developed by “North-West Institute for Non-ferrous metals (NIN)”, Titanium scrap is reacted with hydrogen to form titanium hydride and then ground to fine powder. The titanium powder is prone to contamination from the grinding media, though the process uses conventional technology and equipment Production of titanium metal powder in USA and European Union amount to only few hundred tons per year.

2.4 Indian Scenario

In th Bhabha Atomic Research Centre, Mumbai (BARC) undertook bench scale experiments on static bed chlorination of rutile, batch type distillation equipment for purifying titanium tetrachloride and magnesium reduction of titanium tetrachloride followed by vacuum treatment of the reaction mass to remove magnesium chloride and unreacted magnesium from the titanium sponge. Acid and water leaching of the reacted mass was also tried as an alternative to vacuum treatment. Sodium reduction of titanium tetrachloride followed by water leaching was also attempted in the same set up. The facility was scaled up to 15 kg, batch starting from 1kg, batch and established the process route for both sodium and magnesium reduction of making titanium sponge.

After completing the above study during 1967 to 1973 a pilot plant of 7.5 ton per annum capacity for making titanium sponge was established at Nuclear Fuel Complex at Hyderabad (NFC) with the following facilities:-

1. Fluidized bed chlorinator of 500 kg per day capacity.
2. Batch type equipment for hydrogen sulphide treatment and double stage distillation column for chloride purification of matching capacity.
3. Magnesium reduction and pyro vacuum treatment equipment with a batch capacity of 100 kg titanium sponge
4. Facility for sodium reduction with arrangement for feed liquid sodium capable of producing about 60 kg per batch of titanium sponge.
5. Two stage sodium reduction equipment with capacity of 120 kg.
6. Required sponge handling and processing equipment.

The Pilot plant was operated during the period 1975 to 1978 and generated valuable data on plant operation in sufficiently large scale. Consideration of safety, cost of reductants, comparative ease of handling of the reductants and the possibility of recycling, the by-product magnesium chloride through fused salt electrolysis established the process of magnesium reduction as the preferred choice for making titanium sponge in larger scale.

Based on above experience of pilot plant operation at NFC, a Technology Development Centre for titanium sponge was established at Defence Metallurgical Research Laboratory, Hyderabad (DMRL) in 1984 for developing Kroll Process to a level of commercial viability. A 2000 kg batch Kroll reaction reactor with a continuous purification system for refining titanium tetrachloride through two stages of distillation with a throughput of 150 kg per hour was established.

The reaction mass was subject to pyro-vacuum in a separate vessel at a temperature of 975°C under a dynamic vacuum in the range of 10-2 to 10-3 mm Hg (abs) for removing the magnesium chloride and unreacted magnesium from the titanium sponge. The batch had a cycle time of around 91 hours. In 1992 DMRL developed the combined process titanium sponge production reactor system in which the reduction reaction and vacuum distillation of the magnesium chloride were carried out in the same reactor eliminating the need for transferring the reacted mass to a separate vessel. Process was developed for a 4000 kg. batch titanium sponge production reactor based on combined process in which one 480 kW pit furnace catered to the need of magnesium reduction of titanium tetrachloride and pyro vacuum distillation of reacted mass post reaction. This technology has been adopted in the 500 tpa titanium sponge manufacturing facility set up in Kerala Minerals & Metals Limited (KMML). India became the 7th country to produce titanium sponge, when the 500 tpa production facility at, KMML, Chavara, Kerala, produced the first batch of 3000 kg titanium sponge on 06-09-2011. While developing the technology for titanium sponge on 4-ton batches, DMRL put in considerable efforts to run large scale mono- and bi- polar molten salt electrolytic cells for production of magnesium from by product magnesium chloride. The technology is currently being established at KMML.

As far as production of titanium powder is concerned, NFC had developed a process consisting of hydriding of titanium scrap to brittle hydride, its grinding to powder form and final dehydrogenation at higher temperature to yield titanium powder. The process was licenced to some private entrepreneur who was producing titanium powder in small scale. National Aeronautical Laboratory, Bangalore has also developed technology to produce titanium powder from molten titanium metal. However, production of free-flow globular Ti powder for additive manufacturing is not being produced commercially.

Mishra Dhatu Nigam Limited, Hyderabad (MIDHANI) is the only company in India having large scale facilities for melting of titanium sponge which is so far being imported. It has the facilities to vacuum melt titanium sponge in vacuum Induction arc melting furnace and has other associated facilities such as, electro slag melting, furnace, titanium alloy making furnaces etc. to undertake manufacture and fabrication of titanium alloys. MIDHANI caters to the need of DRDO laboratories as well as industry who are engaged in development and production of aircrafts, helicopters for the defence organizations. MIDHANI has the required facilities to undertake and characterize. The Ti sponge being produced by KMML has been certified for aeronautical applications by DRDO.

- **Challenges for Titanium Production in India**

High cost of production of titanium metal coupled with the technical difficulties associated with its production which involves multiple stages of processing involving handling of corrosive process inputs at high temperature and adoption of complex technically challenging procedures to handle the metal at high temperature in completely inert atmosphere, as it is highly reactive towards the atmospheric gases such as nitrogen and oxygen have been barrier for its large scale industrial production. The production of titanium metal is dominated by a handful of layers whereas at the consumption end a few aerospace industries influence the market as the titanium sponge is manually sorted and made in small batches to cater to their requirements. There is no universally acceptable standard regarding the specification of titanium metal product which is acceptable to all its industrial users.

Each aerospace manufacturer sticks to its specification and the manufacturer cater it to by resorting to special production campaign in small batches. It takes on an average minimum 3 years to get the product of titanium metal of a new producer accepted by the user of an aerospace industry. The titanium sponge specification which is taken from the US National purchase speciation's is given in Annexure-11 for elucidating the rigorous process of sampling and testing the metal product prior to its acceptance for aerospace usage. Indian Standard Specification IS 11901–1986 for titanium sponge along with the Russian specification of titanium sponge GOST 17746-96 are also presented in the same Annexure for the purpose of comparison. It may be noted that the quality of titanium sponge as per the specifications stipulated in the above 3 standards cannot be easily co-related.

Global production of titanium sponge is about 60% of its installed capacity. As a result of which it comes difficult for a new player to enter the market. In addition, the economics of titanium metal industry being closely linked to that of aerospace industry is highly cyclical in nature and at the time of economic downturn the established players can easily survive the downward pressure on the price of titanium sponge owing to the idle production capacity, thus making it difficult for the new entrant to survive during such period of low economic growth.

Economy of titanium metal production largely depends on availability of chlorine and magnesium metal of high purity at competitive price in addition to adoption of the state-of-the-art titanium sponge production technology. Presence of titanium pigment producing industry by chlorine route which produces titanium tetrachloride as an intermediate product is an added advantage for the titanium sponge producing industry as titanium tetrachloride produced for making titanium pigment by chlorine route can be used as a feed stock for the titanium sponge production resulting in saving of capital investment. Cycle time of titanium sponge production batch, level of impurities such as iron, oxygen, nitrogen etc. present in the titanium sponge along with the efficiency of recovering on reacted magnesium from each batch and economy method of disposing of the by-product magnesium chloride considerably affect the market competitiveness of the sponge product. Availability of downstream fabrication facility and the technology for the same to produce titanium ingots and metal sheets form the titanium sponge considerably impact the growth of titanium sponge producing industry. Both the titanium sponge production and titanium metal processing industry complement each other for their economic viability, as processing of metal ingots to titanium sponge uses titanium scrap which is as much as 100% of the quantity of freshly produced sponge and the downstream processing done to produce the finished titanium mill products generate huge quantity of titanium scrap.

Availability of chlorine in India is not a problem as chlor-alkali industry producing caustic soda and chlorine by electrolysis of brine is well established. KMML is the only industry producing titanium pigment by chloride route and hence produces titanium tetrachloride which has been used for manufacturing titanium sponge in the 500 tpa sponge plant set up in KMML's campus. There is at present no magnesium manufacturing unit in India and magnesium metal for production of titanium sponge is imported from overseas i.e., predominantly from China. Magnesium metal of purity more than 99.95% is used for making titanium sponge. The chemical composition of magnesium metal as per Indian Standard IS 6694-1999 is given in Annexure- 12.

DMRL is still in the process of developing electrolysis cell for producing magnesium and chlorine from the magnesium chloride produced in the 500 tpa sponge plant. In the absence of commercially viable technology for producing magnesium and chlorine from the byproduct magnesium chloride suitable mechanism to dispose of the anhydrous magnesium chloride has to be adopted. Titanium sponge manufacturers in USA, Japan, Russia, Ukraine and Kazakhstan have integrated electrolysis facilities for recycling magnesium and chlorine produced by electrolysis of anhydrous magnesium chloride, a byproduct of titanium sponge producing industry. China, which has currently emerged as the major global producer of titanium does not have facilities to recycle magnesium and chlorine by electrolyzing the byproduct magnesium chloride. Chinese producers of titanium sponge dispose of anhydrous magnesium chloride byproduct, the purpose of de-icing European roads during winter. As of 2010, China caters to more than 85% of world magnesium consumption and has more than 80% of global magnesium production capacity. World production of magnesium metal in 2010 is reported to be 7,57,000 tons out of which China's contribution is 6,54,000 tons.

Contrary to the practice followed in USA, Canada, Japan, Russia, Ukraine, China has adopted the Pidgeon process in place of electrolysis to produce magnesium metal from its ore such as dolomite and magnesite. Production of magnesium in China was 25 times in 1999 compared to that in 1980. The magnesium production by Pidgeon process is amenable for adoption in small scale manufacturing and involves high manual labour with low capital investment compared to that by electrolysis. Annexure- 13 gives a comparison of electro chemical process and Pidgeon process for magnesium production.

2.5 India Value Chain v/s Global Value Chain

As elaborated above, with 593.5 Mt of ilmenite and 31.3 Mt of rutile, India has the third largest deposits of titanium ores in the world [Nagesh 2017]. However, it was only in 2012 that a 500 t Ti-sponge plant came into being under funding from ISRO based on DRDO Technology. This plant is hosted and operated by Kerala Minerals and Metals Limited, a state PSU. It uses ilmenite ore mined at the Chavara coast, converted in stages to TiO_2 and then to aerospace grade $TiCl_4$. The technology is based on the time-tested Kroll's process which is basically a magnesiothermic reduction process. It may be mentioned that the indigenous Ti-sponge has been certified by airworthiness agencies.

The outstanding issues with respect to sponge are high price (about $22 per kg) compared to the international price (about $9 per kg in 2019). This is partly related to the facts that: (a) grades other than the top grade, which are not suitable for aerospace use, are difficult to sell, thus adding to the overall price of the sponge and (b) recycling of magnesium which is used as the reductant in the Kroll's process has not yet taken place, although the recycling plant is under installation, based on DMRL knowhow.

There have been several instances where state governments with foreign collaborations have expressed interest in exploiting ilmenite resources of their states to produce Ti-sponge, but none has materialised.

Mishra Dhatu Nigam (Midhani), a Defence PSU has most facilities such as Vacuum Arc Remelting (for making ingots out of Ti-sponge), Forging press (for break down- and shape forging), rolling mill (for flat products), heat treatment etc, required to produce various mill forms mentioned in the introduction.
The installed capacity of Midhani is 300 t mill products, which is projected to increase to 500 t initially, but can go up to 1000 tpa. There are no known firms other than Midhani who have similar capabilities, either in terms of infrastructure or in terms of technology.

- **The following is the scenario as far as Ti based products areconcerned . The following are the known users of titanium and its alloys in India:**

Indian Space Research Organization (ISRO), HAL, Defence Research and Development Organisation (DRDO), Brahmos Aerospace Pvt Limited (an Indo-Russian Joint Venture), and Midhani, all being for aerospace structural and engine applications.
Combat aircraft programmes of the country typically use alloys in bar, plate, sheet, tube, wire and forging forms, involving various processing operations such as melting, casting, forging, extrusion, rolling, ring rolling, cladding, heat treatment, fabrication, and machining. The most common alloys used are Ti-6Al-4V (normal and ELI, i.e., extra low interstitials grade), Ti-5Al-2.5Sn-ELI, VT-14 (Ti-5.4Al-3Mo-1V), Ti-3Al-2.5V and Ti-15V-3Al-Sn-3Cr alloy. Another area of interest is Ti-alloys for demanding environments, such as for hypersonic thermal protection systems, for impact absorbing applications etc.
Applications of electron-beam-welded hemispherical caps to make air bottles (pressure vessels) are being realised in ISRO (see Fig. 2.5.1) [Gupta 2015].

Applications of smart alloys based on Ti such as Nitinol have been realised in hydraulic couplings used in fighter aircrafts. Programmes aimed at higher supersonic aircrafts will further increase proportion of titanium used in the airframe.

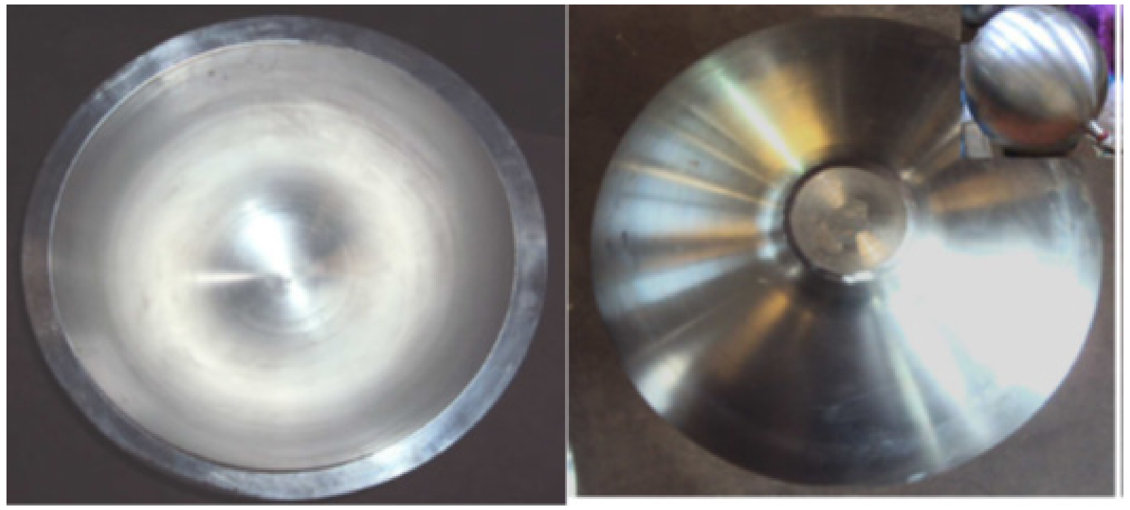

Fig. 2.5.1: Forged & Machined Hemisphere (inset: pressure vessel made out of hemispheres) [Gupta 2015].

The current indigenous efforts of manufacture of aeroengine discs for the licensed production of an aeroengine, using near-isothermal forging process, will culminate during this period. Also, the industrial capability to make beta alloy forgings for landing gear and beta alloy sheets for higher supersonic fighters will mature during the same period. Apart from industrial capability development, the airworthiness certification is also expected to be completed.

In the near future, one can expect launch of development of newer Ti-alloys equivalent to Ti-5553 for landing gear applications in place of Ti-10-2-3 alloy. In Ti-5553, the rate of change of β volume fraction with temperature (below β transus) is low, making it easier to control it within 5-10% for the purpose of optimising between creep and fatigue resistance. Similarly, development of Ti-alloy sheets of compositions equivalent to Beta21S is likely to reach industrial level production to cater to higher supersonic aircraft skin as well as hypersonic applications. Liquid hydrogen tanks made of EB-welded Ti-alloy are suitable for cryogenic engines for satellite launch vehicles. Thus, complete transition to cryogenic propulsion will drive up the requirement of super alpha Ti-alloys, which have good properties at cryogenic temperatures (20K). In terms of processing, hot isostatic pressing of powder Ti-alloys, isothermal forging for complex products will see further growth, apart from EB welding.The other generic areas which will gain importance in the near future are production technologies which are cost competitive for commercial uses, products with higher buy-to-fly ratio to reduce scraps and green processing technologies due to stringent environmental regulations.

Beyond the immediate term, which will also spill over to the medium term, developments in Super Plastic Forming (SPF) and Diffusion Bonding (DB) are expected to reach a level where component trials and evaluations may take place. SPF/DB is not a new concept, and much science has been published [Padmanabham 2018], especially for Ti-alloys (Fig. 2.5.2). However, not significant component development activities are reported. Given the promise of fabrication of complex parts in a single integral process, more efforts in this area are likely to be made. Apart from this, improving the balance of properties such as strength and fracture toughness for beta alloys, improving the balance between strength, creep resistance and LCF resistance for near-α alloys for disc will be pursued.

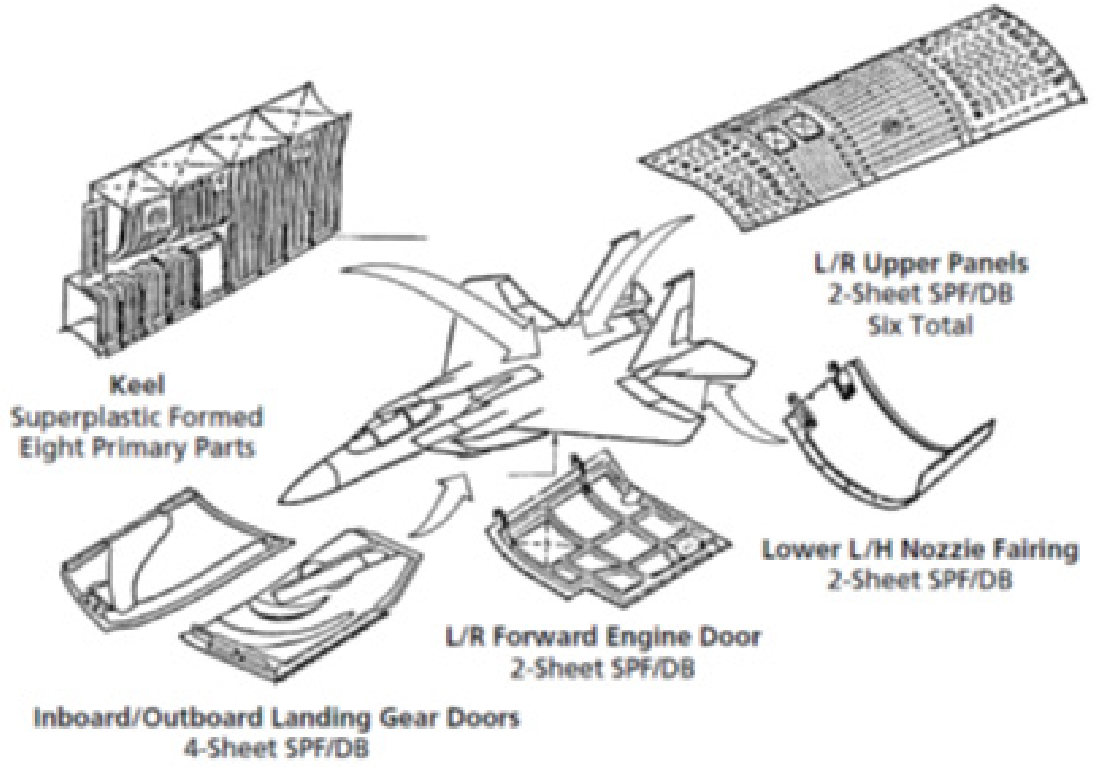

Fig. 2.5.2: SPF and SPF/DB Applications on F-15E [Hefti 2005]

The following areas are likely to pick up in the long term. More products based on shape memory alloys will penetrate the market in biomedical applications as well as in aerospace applications. Since the higher supersonic aircraft being planned in the country are much larger than the current fighter aircraft, more quantities of shape memory alloy hydraulic couplings are expected to be produced.
There is work showing that Ti-alloy components can be made by additive manufacturing (Fig. 2.5.3). However, the dynamic properties of such products have not been adequately demonstrated. Also remain to be answered are questions related to type certification of such products. In the long term, the currently ongoing efforts in understanding the mechanical and corrosion behavior of additively manufactured Ti-alloy components will reach a point of maturity.

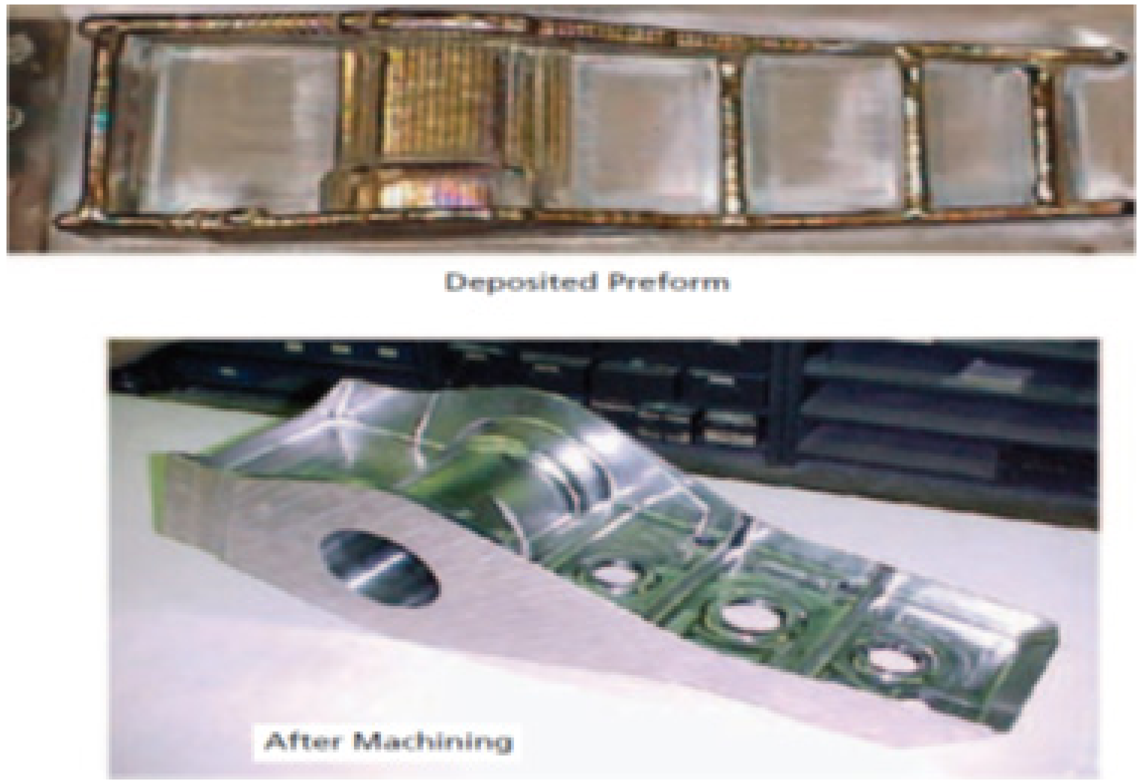

Fig. 2.5.3: Titanium Laser Deposited Rib Section [Campbell 2006]

In the long term, we should see the batch scale of Ti-sponge process to increase from the current 4 t per batch to 8 t per batch. This should also reduce the sponge price and make it competitive to the international price.

2.6 Gap Areas and Recommendations to Fill Gaps

The technology to make Ti sponge as well as alloys exists in India. The technologies to make Ti based aeroengine forgings also exists in India, although it has not been implemented at large industrial scale. Currently Government is considering establishing large scale forge facility for the purpose. The Mg recycling technology needs to be completely established and experienced at plant scale at KMML and necessary upgradations may be made. Scrap recycling expertise does not exist in India, or at least not implemented commercially. There remain certain crucial gaps in indigenous technologies and capabilities.

First, there are no large-scale forging presses in India, this is hindering application of technology for forging aeroengine discs of Kaveri engine class. The crucial challenge here is to generate enough work to keep the press engaged to justify the purchase.
Larger width rolling mills are required to produce plates of adequate width for ISRO as well as Brahmos programmes.
Investment casting of Ti-alloys is not yet fully developed within the country, although PC castings, Lucknow is known to have initiated work in this area. Midhani as well as HAL Koraput have some experience but there are perhaps no continuous orders for such items. If titanium aluminides are to replace Ni-based superalloys, they would be used as investment castings for which this technology is required. There is also a need for a hot isostatic press facility to go along with investment castings to close the casting porosity and achieve properties comparable to forged products.

The technology of additive manufacturing has not reached a maturity level for titanium alloys, possibly due to the reactive nature of titanium and the need to have a protective atmosphere during manufacturing. Also, extensive evaluation and certification of additively manufactured products are a must.

In general, titanium aerospace products require extensive fatigue and creep testing. These tests are time taking. Apart from AMTL in Hyderabad, there is no other place which houses a collection of facilities to evaluate mechanical and corrosion properties of aeronautical materials. Such an infrastructure is required for R&D as well as for routine certification and inspection of items.

In the medium term, the technology of hot isostatic pressing for Ti-components needs to be developed. Further, there is a need to develop wear-resistant coatings for Ti alloys, while for certain applications, cladding technologies are also required.

Skill manpower is probably the most important resource, as the manpower is highly limited among the government laboratories and PSUs. Private industry has recently entered the field both in investment casting technology and is planning to establish downstream processing from Ti sponge onwards. Once these gaps are filled and when regular production of aircraft starts, the supply chain will get strengthened.

2.7 Role of the Stakeholders such as, Government Academia, Industry and Research Institutes

The setting up and operation of 500 tpy sponge by KMML at long last would definitely address the country's present requirement of aero-space grade titanium and its alloys. The plant has however to sort out its operational problems and should be able to generate aerospace grade titanium sponge consistently.

Moreover, the sponge plant has yet to integrate with an additional facility to be set up at the same premises for production of magnesium metal by electrolysis of by-product magnesium chloride. A Project Report to set up a Pilot Plant at Zirconium Complex of NFC, Prazaykayal, Tamil Nadu of capacity – 260 kg magnesium per day through operating two numbers of 8KA bipolar cells was submitted jointly by DMRL and NFC for financial approval in September,2010. The main objective to set up such facility at a capital and operating cost of Rs. 19.1 crores for 18 months is to optimize and ruggedize the technology as developed earlier at DMRL, Hyderabad. This pilot plant would have a series of furnaces for movement of molten magnesium chloride, a vacuum ladle for removal of magnesium from the cell, purification and recycle of chlorine as well as process automation/ data acquisition and instrumentation system. Successful commissioning ant testing of such pilot plant can help in setting up the magnesium plant adjacent to sponge plant of KMML.

As indicated earlier melting and processing of the KMML sponge at MIDHANI would lead to generation of large amount of titanium scrap which can meet the growing requirement of relatively lower grade of titanium for use in Chlor alkali industries, aluminium metal production units, desalination plants as well as materials for biomedical applications and personal leisure industrial segments.
There are industries in India who can deal with fabrication of titanium equipment and parts for catering to the need of above industrial segments. The titanium scrap which will fall short of aerospace applications in terms of its physical properties can be re-melted and used in above industry segments to ensure economic utilization of titanium scrap generated in the process.

While such indigenous efforts are commendable, it is time consuming, and country's requirement of titanium may outgrow the limited production.
Any proposal therefore from country like Russia having long history of titanium metal making to set up a large sized titanium sponge plant in India can be considered seriously.

- **Role of DAE**

The process of making titanium metal from the mineral-ilmenite is a long journey involving production of series of value-added products and processes namely as:

1. up gradation of ilmenite to slag/synthetic rutile
2. conversion of upgraded feed to pure $TiO2$
3. chlorination of oxide feed to $TiCl4$
4. Kroll reduction of $TiCl4$ to Ti sponge
5. Mg and chlorine recycle from $MgCl2$
6. consolidation of sponge to Ti ingot by vac arc melting and

7. recycle of scrap.

Considerable scope exists in introducing innovative green processes in this long technical route with objectives for energy savings and reduction of pollutants. DAE with its multi multi-disciplinary approach and leveraging of available in-house technological expertise through its various units like BARC, IGCAR IREL, HWB, and NFC can be the right agency to address the above issues. Besides DAE, CSIR laboratories and IITs can also participate in above mentioned programmes

- **IREL, Ltd**

The Technology Development Council of IREL is working along this direction and IREL is ready to take on following programmes for implementation on larger scale:

- **Upgradation of Low-Grade Ilmenite of OSCOM**

OSCOM ilmenite with 50% TiO_2 is eminently suited for its carbothermic smelting to two value added products namely sulphatable grade slag with 80% TiO_2 and Pig iron. Setting up of 50 ton/day slag plant at OSCOM premises in collaboration with Bhubaneswar based CSIR laboratory– IMMT is under consideration. Running of such a Demonstration Plant would lead to generation of technological inputs for setting up of a full-scale Slag plant as well as provide feed for production of 99.99% pure TiO_2 as developed by IREL.

- **Production of high purity TiO_2**

R&D program sponsored by IREL's technology development council has developed a process to produce 99.99% pure TiO_2 from Orissa grade ilmenite by opening it up with sulphuric acid followed by solvent extraction. The major problem of such an approach is the generation of large quantity ferrous sulphate and IREL has been able to convert this to pigment grade iron oxide once again by solvent extraction. Alternatively, IREL has option to use the sulphate grade slag as feed for acid digestion with great advantage. A combination of 50 tpd slag plant and 33.3 tpd TiO_2 plant would additionally recover major portion of iron as value added products like pig iron and the remaining as pigment grade iron oxide.

- **NFC**
Production of Metal grade $TiCl_4$

This high pure titanium dioxide on the other hand can be used as a feed stock for producing titanium tetrachloride which is the starting material for making titanium sponge. The titanium tetrachloride produced from high pure titanium dioxide feed stock will not require further refining as needed for that in KMML as the titanium tetrachloride in KMML is produced from synthetic rutile containing minimum 90% titanium dioxide.

Fixed bed chlorination of high pure titanium oxide can be adopted as this process is well established by NFC for production of nuclear grade zirconium tetrachloride from zirconium oxide. Alternatively, R&D program may be undertaken to establish molten salt Titanium chlorination process for producing titanium tetrachloride form high pure titanium dioxide. Fluid bed chlorination process which is adopted in Japan and USA for producing titanium tetrachloride depends on relatively pure titanium dioxide containing feed stock (>95% TiO2) having particle size higher than 75 micrometers whereas molten salt chlorination process is insensitive to the particle size of feed material and the process is easier to control and operate compared to that of fluid bed system. Use of high pure titanium dioxide feed stock in the molten salt chlorination process also eliminates the generation of high volume of solid waste and result in improved yield of titanium tetrachloride products.

- **BARC/IGCAR/HWB**
Production of titanium powder

R&D efforts may be taken to develop process for producing high purity titanium metal powder from 99.99% pure titanium dioxide by reducing it with calcium hydrides. Similar process technology is of value in producing rare earth metals such as, neodymium, samarium from their respective oxides.

- **Sodium reduction of $TiCl_4$ in flame reactor**

It may be worth investing in a R&D program for developing the process of manufacturing titanium in a continuous manner by using a flame reactor for reducing titanium tetrachloride vapor in flame of liquid sodium. DAE has in-house technological expertise not only for handling sodium in both liquid and vapor form but also has running R&D program in development of flame reactors.

- **Modified Thermal process for production of magnesium**

As an alternative to developing technology for producing magnesium by electrolysis of fused magnesium chloride energy efficient thermal process such as Bolzano process for producing magnesium metal by reduction of magnesium oxide with ferrosilicon can be developed as it can be easily adopted in Indian conditions. Magnesium chloride produced in titanium sponge manufacture can be used to produce magnesium oxide by reacting magnesium chloride with sodium hydroxide. The sodium chloride solution which is produced in the reaction is electrolyzed to produce caustic soda and chlorine by well-established and widely practiced caustic soda production process. The process economics can be made favourable if titanium sponge production system is coupled with a nearby chloral alkali industry.

2.8 Recommendations

Modernisation of the Ti sponge plant is needed. Completion of Mg recycling technology at KMML is also to be aimed. Apart from these, in the near term, research and development efforts need to focus in the following areas:

- ATI 425 is an alloy that contains lower Al and V than Ti-6Al-4V, addition of Fe and higher, controlled amounts of O for good combinations of ductility and strength. It is melted using single plasma melt technology (not available in India yet), which eliminates inclusions and provides better chemistry control [Sankaran 2017]. Moreover, this alloy was developed to reduce the cost of fabricating components.

- ATI 425 possesses good cold and hot formability; fatigue strength and FCGR characterization of newer Ti-alloys.
- Formability studies of newer Ti alloys such as Beta21S sheets.
- Recycling of solid Ti-alloy scrap, Flow Forming, High temperature Ti-alloys.
- Identification and development of alternative /new materials for replacing existing materials to reduce weight and to have superior performance.
- Investment casting of Ti-alloy components to near-net shape.
- Master alloys (for V, Mo etc). Currently, all Ti-alloys made in the country use imported master alloys as raw materials.
- In the medium term, the following areas would be important from a research point of view.
- High temperature strength and creep studies of newer Ti-alloys.
- Additive manufacturing
- Welding consumables

In the long term, R&D in Ti-matrix composites for bling (bladed ring) applications and in aluminides for aeroengines will be required. Biomedical products are an emerging market at present but likely to grow over the coming decade. Hence more research, development, production, clinical testing etc will have to be pursued.

2.9 Chapter Contributors

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- Prof. Amol Gokhale (Proposed), Professor, Department of Mechanical Engineering at Indian Institute of Technology Bombay
- Dr R N Patra, Former CMD, Indian Rare Earths Limited (IREL)
- Dr SVS Narayanamurty, GM, Liquid Propulsion Systems Centre (LPSC), ISRO, Thiruvanthapuram
- Dr Ch R V S Nagesh, Head, Extraction Technologies Division, DMRL, DRDO
- Mr U V Gururaja, Mishra Dhatu Nigam
- Prof. Bikramjit Basu, Professor, Materials Research Center, Indian Institute of Science, Bangalore
- Dr Amit Bhattacharjee, Director of Management Studies & Head, Titanium Alloy Group, DMRL, Hyderabad
- Dr. Santanu Dhara , Professor School of Medical Science and Technology, IIT Kharagpur
- Mr Saaqib Raahi, Assistant Director & Scientist B, Metallurgical Engineering Department, Bureau of Indian Standards

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ANNEXURE-1

TITANIUM AND SUBSTITUTE METALS

Metals	Density (Gram/cu.cm)	Tensile-strength (Mega pascal)	Strength to weight ratio	Corrosion rate (mm/year)
Titanium Commercially pure Gr.2	4.5	276	61.3	0.0003
Magnesium Pure	1.7	96.6	56.8	0.3
Steel (316 series)	8.0	228	28.5	0.03
Aluminum Alloy 1199	2.7	34.5	12.8	0.1
Copper Annealed	9.0	33.3	3.7	0.04

ANNEXURE-2

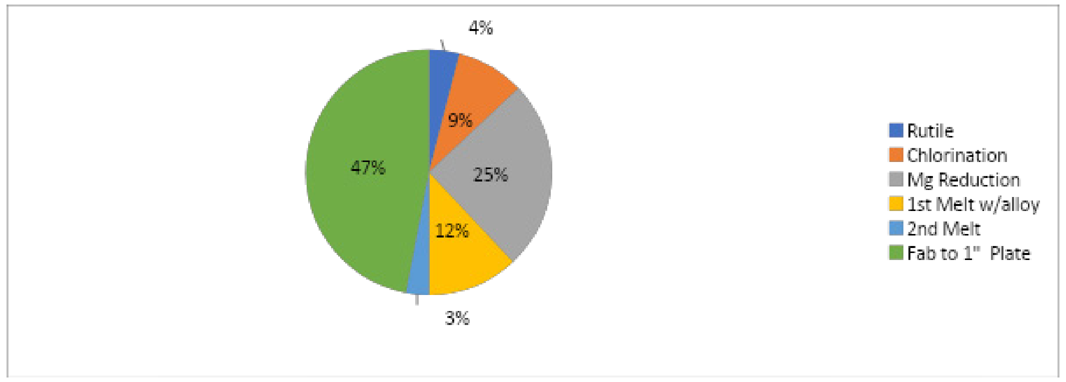
COMPARISON OF MARKET PRICE

USD/KG)

Ore/metal	Titanium	Steel	Aluminum
Ore	Rutile - 2.2	Hematite – 0.1	Bauxite – 0.05 - 0.1
Metal	Sponge – 18.0	0.5	2.1
Ingot	24.0	0.75	2.2
Sheet	35 - 120	1.5 – 3.0	1.9 – 9.5

ANNEXURE – 3

PIE CHART OF TITANIUM COST BREAK UP



Relative Cost Factors for Conventional Mill Processing of 1" Ti Alloy Plate

ANNEXURE – 4

INDUSTRY WISE CONSUMPTION OF RAW STEEL, ALUMINUM, MAGNESIUM AND TITANIUM (2010)

Metal	Construction, building and structural (%)	Transportation and automobiles (%)	Containers and packaging (%)	Special uses (%)	Others (%)
Raw steel	16	15	3	Warehouses and steel service center 25	41
Aluminum	12	34	27	Electrical -8 Machinery-8 Consumer durables - 7	4
Magnesium	40	43		Desulfurization iron and steel 11	6
Titanium	Armor, process equipment, Sports - 34		Aerospace - 66		

ANNEXURE- 5

LIST OF VARIOUS PROCESSES

Process	Brief Description	Remarks
Electronically mediated reaction (EMR)/Molten salt electrolysis (MSE).	TiO_2 is reduced electrolytic ally using carbon anode and calcium nickel alloy as electrolyte	
Fay Farthing and Chen (FFC) Cambridge process.	Electrolytic reduction of pigment grade TiO_2 in molten calcium chloride electrolyte	Funding from USA department of defense for pilot scale plant
Dow Chemical and Howmet (DH) Titanium Company.	Titanium tetrachloride electrolysis using KCl and LiCl electrolyte at 520oc	DH Titanium invested millions of dollars.
Ginatta Electrolytic process	Titanium tetrachloride electrolysis using halide electrolyte, liquid titanium cathode at high temperature	RMI built USD 40 million plant
BHP Billiton	TiO_2 reduction in calcium chloride bath	1 kg per hour facility is being built.
MER Corporation	TiO_2 electrolytic reduction using mixed halide electrolyte. Even ilmenite can be used.	
OS process Prof. Ono and Prof. Suzuki, Japan.	Calciothermic reduction of TiO_2 by electrolytic generation of calcium using carbon anode and calcium chloride electrolyte.	
QIT(Cardarelli Process)	Electrolysis of sulfatable titanium slag containing 75% TiO_2 using calcium fluoride electrolyte. Fe, Cr, Mn, V are removed in 1st stage and molten Ti metal is formed in 2nd stage.	
Armstrong process	Continuous reduction of titanium tetrachloride vapor in liquid sodium by using concentric nozzle flame reactor. Titanium powder is produced.	International titanium powder LLC (ITP), a wholly owned subsidiary of Crystal Global, Jeddah, Saudi Arabia is setting up 2000 tpa plant.
SRI International	High-temperature fluid bed reduction of titanium tetra chloride by hydrogen. Metal alloys deposited in a particle substrate	Received funding from USA Department of Defense
Idaho Titanium Technologies (ITT)	Thermal dissociation and reduction of titanium tetra chloride by hydrogen. Product is titanium hydride powder	
CSIR, South Africa	Titanium tetrachloride reduction by hydrogen to titanium in molten salt medium	
Vartech Inc	Reduction of titanium tetra chloride by a gaseous reducing agent in an inert atmosphere to make titanium powder.	
Idaho Research Centre Foundation	Titanium tetrachloride is ground with calcium hydride to obtain titanium hydride in mechano chemical process.	
ADMA process, USA	Kroll process titanium sponge is reacted with hydrogen for making titanium hydride suitable for powder metallurgical processing.	
Peruke process, South Africa (AlTi process)	Aluminum reduction of sodium/potassium fluoro titanate.	
JTS process, Japan	Titanium tetrachloride reduction by calcium in plasma reactor for separating calcium chloride from titanium metal in molten state.	

TiRo (CSIRO Australia)	Fluidized bed reduction of titanium tetrachloride using magnesium vapor.	
DMR	Alumino Thermic process to convert TiO2.	
Dupont	Sodium reduction of titanium tetrachloride.	
MIR Chem	TiO2 granules reduced by iodine in shaking reactor.	
MIT Titanium initiative	Electrolytic reduction of TiO2 in oxide melt.	
Norsk	Calciothermic reduction of titanium tetrachloride.	
Norton Wheel	Electrolytic cell for titanium carbide.	
Preform reduction process	Reduction of TiO2 by calcium.	
Rhone Poulenc	Lithium reduction titanium tetrachloride.	

ANNEXURE-6

COMPARISON OF SPECIFIC PROCESS INPUTS FOR FIXED AND FLUIDIZED BED CHLORINATION.

Process inputs	Fixed bed	Fluidized bed
Petroleum coke (Kg/TiCl4 ton)	180	90
Chlorine (Kg/TiCl4 ton)	880	800
Energy (X103 Kcal/TiCl4 ton)	1560	500
Titanium yield (%)	95	98

ANNEXURE-7

COMPARISON OF HUNTER PROCESS AND KROLL PROCESS

Kroll Process	Hunter Process
Production is in batch mode Titanium tetrachloride does not dissolving magnesium.	Production can be semi continuous as titanium di-chloride an intermediate reduction product is soluble in sodium. First stage reduction of titanium tetrachloride to di-chloride is achieved in a continuous stir tank reactor, whereas the final stage of reduction to titanium sponge using sodium is done in a batch manner.
15 to 30% excess above stoichiometric requirement of magnesium is used.	Marginal excess above stoichiometric requirement of titanium tetrachloride is used.
Fines are not formed in the products	Up to 10% fines is produced
Difficult to grind	Easy to grind
The bottom and outer layer in contact with reactor wall is contaminated with iron	Iron contamination is much less
Titanium sponge is leached, or vacuum distilled.	Titanium sponge is only leached.
Reactor contains mostly titanium sponge after vacuum distillation.	Reactor contains high amount of sodium chloride along with titanium sponge after reaction is completed.
33% less energy compared to sodium required to generate magnesium from anhydrous magnesium chloride	Energy requirement higher to generate sodium from sodium chloride as it is in aqueous solution.

ANNEXURE-8

COMPARISON WITH EARLIER AND COMBINED PROCESS (DMRL)

Description	Earlier process	Combined process
Titanium recovery	91%	98%
Magnesium recovery	92%	99%
Chlorine recovery	75%	93%
Titanium sponge power requirement	37000 kwh/ton Ti sponge (38000 kwh/ton Ti sponge) *	17000 kwh/ton Ti sponge (27000 kwh/ton Ti sponge) *
Magnesium power requirement	18000 kwh/ton Ti sponge (28000 kwh/ton Ti sponge) *	10000 kwh/ton Ti sponge (21000 kwh/ton Ti sponge) *

ANNEXURE-9
TITANIUM SPONGE PLANT – COUNTRY WISE LIST

A. Japan
1. Osaka Titanium Technologies
2. Toho Titanium Company Ltd

B. USA
1. Titanium Metals Corporation (TIMET)
2. Allegheny Technologies Inc
3. RTI International Metals Inc
4. Honeywell Electronic Materials

C. **Kazakhstan**
1. UST Kamenogorsk Titanium & Magnesium Plant (UKTMP)

D. Russia
1. VISMPO Avisma
2. Solikamsk Magnesium
3. Kulchevsky Ferroalloy Plant

E. Ukraine
1. Zaporzhye Titanium & Magnesium combine (ZTMK)

F. China
1. Zunyi Titanium Stork Company
2. Fushun Jinming Titanium
3. Jinzhou Huatai Ferroalloys
4. Baoti Huashen Titanium Industry
5. Chaoyang Hundred Sheng Company
6. Tongshan Tianhe Titanium Industry
7. Chaoyang Jinda

ANNEXURE – 10

SPECIFICATION OF TITANIUM METAL POWDER (JSC POLEMA, RUSSIA)

GRADES AND CHEMICAL COMPOSITION

Grades	Ti	Admixtures, mass %, maximum					
		N	C	H	Fe+Ni	Si	Cl
RP-Ti grade K-1	base	0,07	0,05	0,35	0,35	0,10	0,003
RP-Ti grade S-1	base	0,08	0,05	0,35	0,40	0,10	0,004
RP-Ti grade M-1	base	0,08	0,05	0,35	0,40	0,10	0,004
RP-Ti grade OM-1	base	0,08	0,05	0,40	0,40	0,10	0,004
RP-Ti grade K-2	base	0,20	0,05	0,35	0,35	1,00	0,003
RP-Ti grade S-2	base	0,20	0,05	0,35	0,40	1,00	0,004
RP-Ti grade OM-2 RP-Ti grade M (A)-2	base	0,08	0,05	0,35	0,40	0,10	0,004
RP-Ti grade OM-1	base	0,20	0,05	0,40	0,40	1,00	0,004

Sample chemical composition of RP-Ti grade M-1 powder

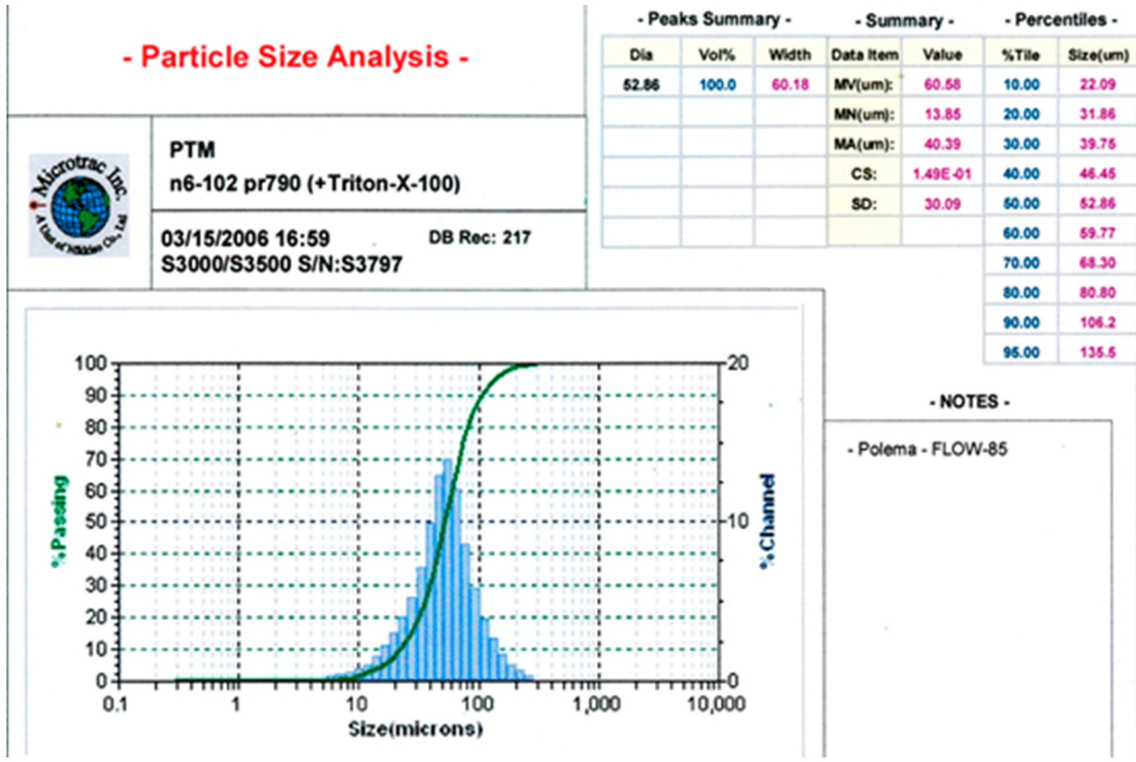
№	Ti	Admixtures, mass %									
		C	O	N	S	Ca	Fe	Ni	Si	Al	Mg
1	base	0,046	0,25	0,08	0,002	0,22	0,050	0,17	0,040	0,01	<0,01
2	base	0,024	0,30	0,060	0,002	0,18	0,040	0,057	0,038	0,05	<0,01
3	base	0,045	0,28	0,050	0,003	0,30	0,030	0,040	0,032	<0,02	<0,02

PARTICLE SIZE, PACKED DENSITY AND COMPRESSIBILITY OF POWDERS

Grades	Granulometric composition, mass %, by fraction, micron				Packed density, g/cm3 *	Pressure of MPa *	
	+280	+100	+45(40)	-45(40)		200	600
RP-Ti grade K	≤ 5,0	Balance (remainder)		≤ 10	0,89	2,70	3,50
RP-Ti grade S	≤ 1,0	Не опр.	≥ 25 (35)	Balance	1,15	2,60	3,24
RP-Ti grade M	0,0	≤ 2,0	≥ 15(25)	Balance	1,02	2,44	3,35
RP-Ti grade OM	0,0	≤ 1,0	≤ 5,0 (5,0)	Balance	1,36	2,72	3,48

* Average values (reference data)

Technical Specifications (TS) establish the packed density norm for RP-Ti grade K powder: 0.6-1.0 g/cm3 and the standardized granulometric composition for the powder RP-Ti grade M (A): +280 microns - 0.0%, +100 microns ≤ 1.0%, +45 microns – 15-40% (+40 microns – 25-50%), -45 (40) microns – remainder.



At the client's request, other requirements are possible for the chemical and granulometric compositions. In particular, for plasma coating deposition, a titanium product is produced with fractions of 40-100, 40-140, and 63-160 microns.

Appendix H

TITANIUM SPONGE SPECIFICATIONS

The following material is an excerpt from U. S. National Stockpile Purchase specification P-97-R7 June 2, 1982 (supersedes P-97-R6, October 19, 1977):

This specification covers titanium metal sponge in the form and quality satisfactory for stockpiling and intended industrial uses.

CHEMICAL AND PHYSICAL REQUIREMENTS

Each lot of titanium purchased under this specification shall be uniform in appearance and thoroughly blended. It shall be free of inclusions, oxides, nitrides, and other contaminants, and shall have a uniform matte gray color. Deviations from this color, such as bluish or yellowish hues, may indicate the presence of excessive amounts of impurities and the need for micro-samples to be taken for chemical analysis. The material purchased shall conform to the following applicable chemical and physical requirements:

A. Chemical Requirements:

Percent by Weight (Dry Basis)[a]

Element		Grade 1A-0[b] Type A	Grade 1A-0[b] Type B	Grade 1A-0[b] Type C	Grade 1B-0[b] Type A
Nitrogen	Max.	0.010	0.015	0.015	0.008
Carbon	Max.	0.020	0.025	0.020	0.020
Sodium (total)	Max.	-	-	0.19	0.01
Magnesium	Max.	0.08	0.50		0.08
Lithium	Max.	-	-	-	0.09
Potassium	Max.	-	-	-	-
Aluminum	Max.	-	0.07	-	-
Chlorine	Max.	0.10	0.20	0.20	0.10

Chemical Requirements (continued):

Percent by Weight (Dry Basis)[a]

Element		Grade 1A-0[b] Type A	Grade 1A-0[b] Type B	Grade 1A-0[b] Type C	Grade 1B-0[b] Type A
Iron	Max.	0.08	0.10	0.04	0.04
Silicon	Max.	0.04	0.04	0.04	0.04
Hydrogen	Max.	0.005	0.03	0.05	0.02
Oxygen	Max.	0.10	0.10	0.10	0.07
Water	Max.	0.02	0.02	0.02	0.02
All other elements (total)	Max.	0.05	0.05	0.05	0.05
Titanium (nominally)	Min.	99.6	99.1	99.3	99.6

a The sample shall be dried for 2 hours at 135°C.

b Type A Magnesium reduced and finished by vacuum distillation.
Type B Magnesium reduced and finished by acid leaching or inert gas sweep distillation.
Type C Sodium reduced and finished by acid leaching.

B. Physical Requirements:

Hardness (BHN):

The maximum Brinell hardness of each lot of Type A and Type D titanium shall be 100, and each lot of Type B and Type C titanium shall be 120.

The Brinell hardness of a lot shall be the average of the hardness determinations made on button representing the lot of titanium. However, no batch having a Brinell hardness more than 10 points above the maximum allowable for the lot shall be used in blending for that lot. The method of measurement shall be in accordance with ASTM Method E10, Test for Brinell Hardness of Metallic Materials, using a 10-mm ball, 1500-kgf load in the 100 to 200 Bhn range and a 500-kgf load in the under 95 Bhn range and a 30-s dwell.

Note: P-97-R7 also contains Section III on Packaging, Marking, Identification, Shipping and Handling.

The following material is an excerpt from ASTM B-299-74:
(ASTM B-299-80 is in preparation)

STANDARD SPECIFICATION FOR TITANIUM SPONGE

This specification covers virgin titanium metal melting stock. This virgin metal is commonly designated as sponge titanium because of its porous, spongelike texture.

Manufacture

Sponge titanium is usually prepared by reduction of titanium tetrachloride and gets its spongelike character from the processes involved in production. This spongy characteristic, however; is not considered essential and may be expected to vary greatly with manufacturing methods. The metal is usually supplied in lumps of 1/2 inch (12.7 mm) or less in size. This specification, however, is not limited to metal prepared by reduction of the tetrachloride or to material of the size indicated.

Only virgin titanium, free of scrap and intentionally added contaminants, shall be supplied under this specification. It shall be supplied in uniform, well-mixed blends, each of which shall be clearly designated.

Sampling

The sampling method used shall be a matter of agreement between the manufacturer and the purchaser. The following are acceptable industrial practices:

The sample for determining the conformance of the lot to the chemical and physical requirements shall be obtained by sampling to produce a 0.50 percent sample but not less than 30 lb (14 kg). The blended evaluation sample shall be compacted into consumable electrodes for melting. A portion of the compact shall be sawed off prior to melting and sampled by drilling for the analysis of magnesium, sodium, chlorine, and hydrogen. The electrode shall be melted under an inert atmosphere in a vacuum to form an ingot. The resulting ingot shall be sampled by sawing a transverse section approximately 1/2 inch (12.7 mm) thick from the center of the ingot. After machining both sides of this slab, five analyses and five hardness readings are to be made at locations equal distances apart and diagonally across the machined surfaces. Slices 1/4 inch (6.35 mm) wide are to be taken from this slab, parallel to the hardness locations, and sheared to obtain samples weighing approximately 0.1 g. for oxygen and nitrogen analysis. One half of the slab shall accompany the shipment and the other half shall be retained by the manufacturer.

Chemical Requirements

The titanium metal supplied under this specification shall conform to the chemical composition requirements prescribed in the Table below.

Element	Weight percent (dry basis)			
	MD-120	ML-120	SL-120	GP-1
Nitrogen, max	0.015	0.015	0.015	0.020
Carbon, max	0.020	0.025	0.020	0.025
Sodium, max (total)	-	-	0.19	-
Magnesium, max	0.05	0.50	-	-
Chlorine, max	0.12	0.20	0.20	0.20
Iron, max	0.12	0.15	0.05	0.25
Silicon, max	0.04	0.04	0.04	0.04
Hydrogen, max	0.010	0.03	0.05	0.03
Oxygen, max	0.10	0.10	0.10	0.15
All other impurities (total), max	0.05	0.05	0.05	0.05
Titanium, balance (nominal)	99.3	99.1	99.3	-

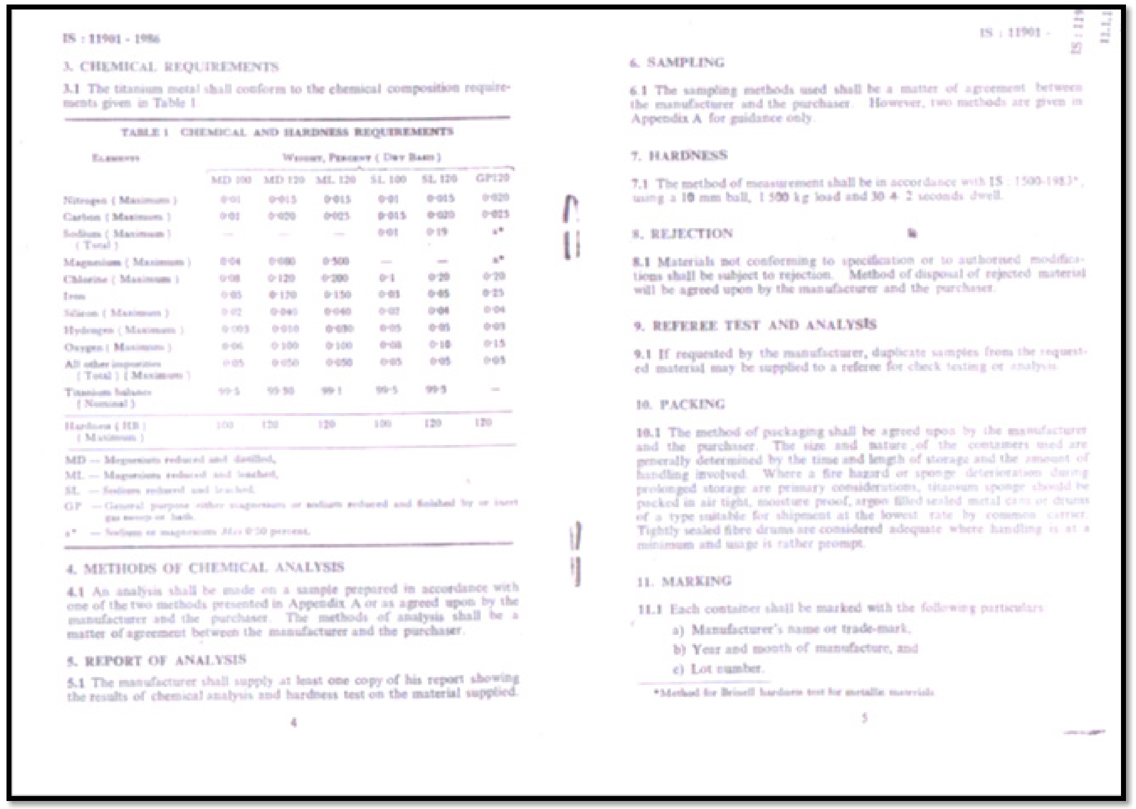
MD-120 Magnesium-reduced and finished by distillation.
ML-120 Magnesium-reduced and finished by leaching or inert gas sweep.
SL-120 Sodium-reduced and finished by leaching. Sodium or magnesium, max: 0.50 percent.
GP-1A general purpose grade, either magnesium, or sodium-reduced and finished by leaching or inert gas sweep or both.

Methods of Chemical Analysis

The methods of analysis shall be in accordance with ASTM Methods E 120, Chemical Analysis of Titanium and Titanium Alloys, or as agreed upon by the manufacturer and the purchaser.

Hardness

The Brinell hardness of a lot shall be the average of the hardness determinations made on the solid samples prepared as described in Section 4 and the hardness value shall not exceed 120 HB. The method of measurement shall be in accordance with ASTM Method E10 Test for Brinell Hardness of Metallic Materials using a 10-mm ball, 1500-kgf load, and a 30-s dwell.



IS : 11901 - 1986

3. CHEMICAL REQUIREMENTS

3.1 The titanium metal shall conform to the chemical composition requirements given in Table 1.

TABLE 1 CHEMICAL AND HARDNESS REQUIREMENTS

Elements	Weight, Percent (Dry Basis)					
	MD 100	MD 120	ML 120	SL 100	SL 120	GP120
Nitrogen (Maximum)	0·01	0·015	0·015	0·01	0·015	0·020
Carbon (Maximum)	0·01	0·020	0·025	0·015	0·020	0·025
Sodium (Maximum) (Total)	—	—	—	0·01	0·19	a*
Magnesium (Maximum)	0·04	0·080	0·500	—	—	a*
Chlorine (Maximum)	0·08	0·120	0·200	0·1	0·20	0·20
Iron	0·05	0·120	0·150	0·03	0·05	0·25
Silicon (Maximum)	0·02	0·040	0·040	0·02	0·04	0·04
Hydrogen (Maximum)	0·005	0·010	0·030	0·05	0·05	0·05
Oxygen (Maximum)	0·06	0·100	0·100	0·08	0·10	0·15
All other impurities (Total) (Maximum)	0·05	0·050	0·050	0·05	0·05	0·05
Titanium balance (Nominal)	99·5	99·50	99·1	99·5	99·5	—
Hardness (HB) (Maximum)	100	120	120	100	120	120

MD — Magnesium reduced and distilled,

ML — Magnesium reduced and leached,

SL — Sodium reduced and leached,

GP — General purpose either magnesium or sodium reduced and finished by or inert gas sweep or both.

a* — Sodium or magnesium *Max* 0·50 percent.

4. METHODS OF CHEMICAL ANALYSIS

4.1 An analysis shall be made on a sample prepared in accordance with one of the two methods presented in Appendix A or as agreed upon by the manufacturer and the purchaser. The methods of analysis shall be a matter of agreement between the manufacturer and the purchaser.

5. REPORT OF ANALYSIS

5.1 The manufacturer shall supply at least one copy of his report showing the results of chemical analysis and hardness test on the material supplied.

4

IS : 11901 -

6. SAMPLING

6.1 The sampling methods used shall be a matter of agreement between the manufacturer and the purchaser. However, two methods are given in Appendix A for guidance only.

7. HARDNESS

7.1 The method of measurement shall be in accordance with IS : 1500-1983*, using a 10 mm ball, 1 500 kg load and 30 ± 2 seconds dwell.

8. REJECTION

8.1 Materials not conforming to specification or to authorised modifications shall be subject to rejection. Method of disposal of rejected material will be agreed upon by the manufacturer and the purchaser.

9. REFEREE TEST AND ANALYSIS

9.1 If requested by the manufacturer, duplicate samples from the requested material may be supplied to a referee for check testing or analysis.

10. PACKING

10.1 The method of packaging shall be agreed upon by the manufacturer and the purchaser. The size and nature of the containers used are generally determined by the time and length of storage and the amount of handling involved. Where a fire hazard or sponge deterioration during prolonged storage are primary considerations, titanium sponge should be packed in air tight, moisture proof, argon filled sealed metal cans or drums of a type suitable for shipment at the lowest rate by common carrier. Tightly sealed fibre drums are considered adequate where handling is at a minimum and usage is rather prompt.

11. MARKING

11.1 Each container shall be marked with the following particulars:

a) Manufacturer's name or trade-mark,

b) Year and month of manufacture, and

c) Lot number.

*Method for Brinell hardness test for metallic materials.

5

PRODUCTION OF TITANIUM SPONGE WITH THE REQUIREMENT OF GOST 17746-96.

Grade	Ti % min.	Chemical composition, % max.				Hardness HB, max.
		FE	C	O	N	
TG-90	99,74	0,05	0,02	0,04	0,02	90
TG-100	99,72	0,06	0,03	0,04	0,02	100
TG-110	99,67	0,09	0,03	0,05	0,02	110
TG-120	99,64	0,11	0,03	0,06	0,02	120
TG-130	99,56	0,13	0,03	0,08	0,03	130
TG-150	99,45	0,20	0,03	0,10	0,03	150
TG-Tv	97,75	1,90	0,10	0,10	-	-

ANNEXURE-12

CHEMICAL COMPOSITION OF MAGNESIUM METAL AS PER INDIAN STANDARD IS 6694-1999

Sl. No.	Grades	Maximum permissible impurities in ppm (1000 ppm = 0.1 percent)																	
		Al	Mn	Zn	Si	Cu	Fe	Ni	Pb	Sn	Ca	Cl	B	N	Cd	(Fe+Ni+Cu)	Na	Others (Total)	Total
(1)	(2)	(3)	(4)		(5)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1)	Mg 9995	100	100	100	100	50	30	10	50	50	50	50	-	-	-	50	10	100	500
2)	Mg 9998	40	20	50	30	5	20	5	50	50	30	30	-	10	-	20	10	0	200

ANNEXURE – 13

COMPARISON OF ELECTRO CHEMICAL PROCESS AND PIDGEON PROCESS FOR MAGNESIUM PRODUCTION.

Electrochemical process	**Pidgeon Process**
Less manpower required. 1000ton magnesium production per year per employee.	Manower requirement is comparatively high. 25ton magnesium production per year per employee.
High cost of capital investment needed.	1/10th of the capital investment compared to new electro chemical plants.
Size of plant is sensitive to economy in production of magnesium metal. Larger size is more economical to operate and own.	Size of plant is less sensitive to economy in production. It is possible to build plants with small output i.e., 500 – 3000 tpa.
Operating costs are lower. Energy consumption is reported to be 13000 kwh per ton. of magnesium Electrical energy is needed for operation of the cell.	Operating costs are higher. Energy consumption is reported to be 30000 kwh per ton of magnesium. 14 – 20t Coal is used for production of 1 ton of magnesium and is the principal source of energy.
Stringent feed preparation is necessary for optimum performance of the cells.	Minimum feed pre-treatment is done. Dolomite ore is directly used.

CHAPTER 3:

CERAMICS

3.1 Material and its Background:

Ceramics and glass have shaped the history of human civilization over millennia. From ancient footprints of developments in ceramics and glass in archeologically excavated sites in Egypt, Mesopotamia, India, and China to modern times, there has been a distinct transition from the craft of making ceramic pottery, jewelry, and decorative artwork to engineering ceramics for a variety of advanced technological applications. In most developed and developing economies, the usage of engineering ceramics encompasses a wide gamut of applications, such as structural, environmental, energy generation, healthcare, automotive, aerospace, sensors & actuators, electronics & telecommunication, defense, and so on.

The primary demand for ceramics stems from their superior thermal properties (thermal shock resistance), mechanical properties (higher hardness and compressive strength), tribological properties (lower wear rate), and corrosion resistant properties both at ambient temperature and high temperature and lower density compared to high-temperature metallic alloys currently in use as shown in Figure 1 below.

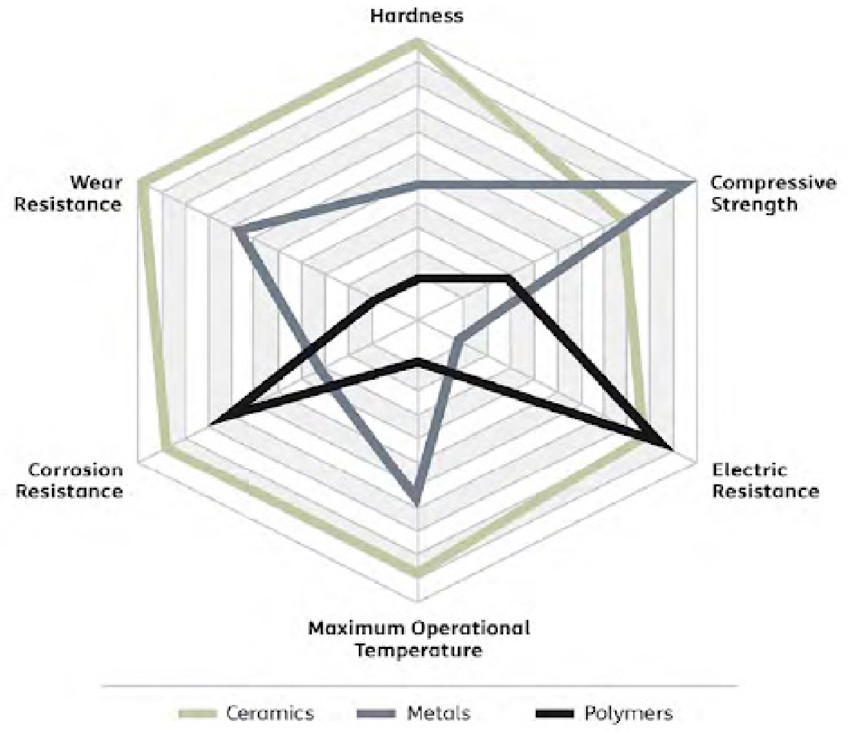


Figure 3.1.1 Properties of advanced ceramics vis a vis metals and polymers

With a global market of USD 100 billion, the ceramic industry demands a great deal of attention and focus in the Indian context, especially, as it has risen to the fifth largest economy in the world surpassing the UK as reported by the International Monetary Fund (IMF) recently.

Deeply intertwined with the ceramics sector are those of glass and optical fibers. Overlapping technological elements and application domains invariably results in concurrent market dynamics that often make it impossible to separate the two verticals. It has therefore been felt pertinent in this report to consider them in unison.

3.2 Global Value Chain

The global value chain in ceramics appears to be disparate. It varies from sector to sector in volume, composition, and overall resilience.
The global value chain for advanced ceramics and composites is spread across

continents, namely, North America, Europe, and Asia with the USA, Germany, UK, France, Spain, Italy, and Japan among the largest contributors. The US market for advanced ceramics is estimated at $16 billion which has grown almost 200% in the last decade and a half. The European market for advanced ceramics is estimated at € 28 billion. The Japanese growth of sophisticated, high-quality, high-performance, and innovative ceramics, coined "fine ceramics" is expected to reach ¥ 2 trillion in near future [Source: TIFAC Report on Technology Roadmap Materials 2035 (2015)].

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China is the leader in REE production with over (~60%) share followed by the USA with a share of around (~15%), followed by Myanmar, Australia, Thailand, Madagascar, India (~1%), Russia, Brazil, Vietnam, etc. as per the information available in open source.

In the sector of energy materials, research on SOFC has reached a reasonably matured level and is in use, particularly in advanced countries like the USA, Canada, Germany, the UK, Denmark, Australia, Japan, etc., for various applications. More than $ 50 billion has been invested in engineering, research & development activities worldwide with the US DoE, and EU Joint Undertaking being the key players.

Coming to electro-ceramics, Japan, Germany, China, Sweden, the U.K., and the USA are the major countries presently dominating the global gas sensing markets. Among the industries, some of the key players are Figaro, FIS, Honeywell International, Rockwell Automation, NXP Semiconductors, STMicroelectronics, ABB, Texas Instruments, Amphenol Corporation, Siemens, First Sensor, Hanwei, Denso Corp, Capteur and Bosch.

Finally, North America dominates the global bio-ceramics market followed by Europe and in Asia, China is expected to assume the lead over other countries. Further, most ASEAN countries, including India, primarily depend on imports from the US and Europe.

Some Key Players

Some of the major players operating in the global market include 3M (Ceradyne Inc.), AGC Inc., Applied Ceramics, Blasch Precision., COI Ceramics, Coorstek., Corning Incorporated, International Ceramics, Kyocera Corporation, MARUWA, Materion Corporation, Morgan Advanced Materials, Murata Manufacturing, Rauschert GmbH, Saint-Gobain, Carborundum Universal, Midlands Industrial Ceramic Group and Wonik QnC. The financials for some companies are reported in Table 1

Table 1 Financials of Leading Advanced Ceramics Manufacturers

Company	Net Worth (2021-22)
McDanel Advanced Ceramic Technologies	$ 8.50 Million
AGC Inc.	$ 7.72 Billion
Advanced Ceramics	$ 83.00 Billion
Kyocera Corporation	$ 22.23 Billion
Murata Manufacturing	$ 33.05 Billion
Saint-Gobain	$ 19.98 Billion

[Source: www.companiesmarketcap.com]

Corning Incorporated (US), Prysmian Group (Italy), Sumitomo Electric Industries, Ltd. (Japan), Yangtze Optical Fibre and Cable Joint Stock Limited Company (China), and Fujikura Ltd. (Japan) are some of the key players in the optical fiber domain.
The key industries/sectors for large-scale application of ceramics are building and construction, power generation, metal and material processing, automotive, aerospace, defense, and nuclear.

Key Application Areas

The key application areas for ceramics are enlisted below.

Application Areas	Components
Household appliances	Porcelain enamel coatings for major appliances, glass fiber insulation for stoves and refrigerators, electrical ceramics, glassceramic stove tops, spiral resistance heaters for toaster, ovens etc
Agricultural mechanization	Refractory ceramic containers make melting and forming of ferrous and nonferrous metals possible
Telecommunication	Glass tubes (CRTs), glass faceplate, phosphor coatings, and electrical components, optical fibers
Automobile	Spark plugs, catalytic converters, windows, engine components, sensors, electrical devices etc., turbochargers, wear pads, valves, valve guides, cylinder lines, exhaust liners, bearings etc.
Building & construction	Ceramic floortiles, walltiles and rooftiles, sanitaryware, tableware etc.
Environment	Ceramic membrane for water filtration and effluent treatment
Metal & Materials Processing	Ceramic refractories for iron & steel industries, nonferrous metal processing industries etc.
Energy Generation	Piezoactuators, ceramic insulators
Healthcare	Replacement joints, heart valves, bone substitutes, hearing aids, pacemakers, dental ceramics, transducers for ultrasound diagnostics, ceramic scintillator for X-ray CT etc
Engineering & Technical	Cutting tools, seals, thread guides, gun barrel liners, extrusion dies etc.
Defense	Vehicular and body armor panels for military applications
Aerospace	Missile radomes, heat exchanger tubes and parts, thermal protective coatings, weld nozzles, aircraft brake discs, furnace parts etc., components in scramjet propulsion, rocket propulsion, nozzles and nose cones for re-entry launch vehicles etc.

Table 2: Application areas and components made of ceramics:

Size of Market

According to a report of Grandview Research, the advanced ceramics and composites market is divided into several key segments as shown in Figure 3.2.1. The largest segment of the advanced ceramics market is electronics & electrical, followed by chemical, transportation, and industrial. A smaller share of the market segment is claimed by medical, defense & security, and various others.
[Source: Advanced ceramics – an industry of the future, Midlands Industrial Ceramics Group, UK (2021)].

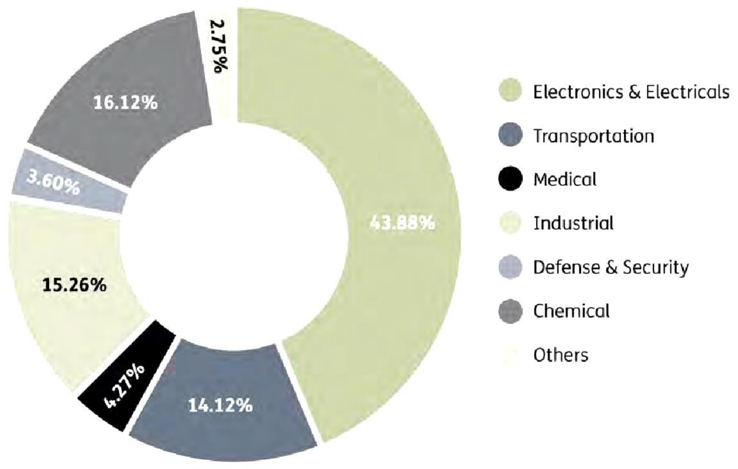

Figure 3.2.1: Advanced ceramics and composites market is divided into several key segments.
[Source: Mordor Intelligence Analysis (2017-2025)]

The global market size for advanced ceramics and composites is estimated at $103.44 billion in 2021 and is expected to grow at CAGR 4.1% to $ 148.5 billion by 2030 [Source: Polaris Market Research Report: Advanced Ceramics Segment Forecast (2022-2030)].

Economic Externalities

An externality as we know is a cost or benefit caused by a producer that is not financially incurred or received by that producer. Externalities are further incidental to an individual, organization, or society as a whole and assume either positive or negative values.
Ceramic industries exhibit a large degree of a negative externality in terms of their highly polluting nature; manpower-intensive nature; and rather vulnerable supply chains for manufacturing processes.

Some Key Elements	Features
Raw Materials	Non-availability of high-quality raw materials at reasonable costs Increasing costs of raw materials
Environmental issues	Issues related to air pollution, GHG emissions, unclean effluents, waste generation (including solid waste) Low awareness at the worker level and unhealthy working conditions
Social issues	Occupational hazards among workers with a high incidence of silicosis and tuberculosis Lack of skilled manpower
Energy	High fuel costs and non-availability of clean fuel Lack of uninterrupted power supply to run the kilns
Imports from China	Significant increase in the volume of dumped imports for vitrified tiles from China that is 25% lower than normal value

[Ref: Indian Ceramics Industry 2022: Status Quo Outlook]

Techno-Commercial Considerations

The ceramic industries are high energy and capital intensive. A significant amount of the cost of manufacturing ceramic items goes in the form of CAPEX and OPEX for communition of lumps into powders, colloidal processing of slurries, high-temperature sintering, cutting, grinding, and machining of ceramic blanks to shaped components, pollution mitigation measures and so on. Developed economies (such as European Union) have laid a great deal of emphasis on improving the techno-economics of ceramic production in the form of energy-efficient and sustainable technologies that are environmentally benign.

3.3 Indian Scenario

National Context

Indian ceramic industry is growing at 9% CAGR and has become a 7.5 billion Euro industry in 2022 [Source: Indian Ceramic Industry: Status Quo and Outlook (2022), published by Messe Muenchen India and EAC International Consulting].

A dominant share of the Indian ceramic market is captured by the ceramic tile industry (market size 3.8 billion Euro with an installed capacity of 955 MIO sq. m.]. India is the second largest global producer of ceramic tiles, sanitaryware, and tableware accounting for 7% of the global production, with an Rs. 26,500 crore market set to grow at 9% in the current decade. The segmentation of the ceramic industry covers tiles, sanitary ware, tableware, and technical ceramics, which have a relative market share of approximately 73.6%, 15%, 8.4%, and 3% respectively.

Morbi, a small town in Gujarat, traditionally made tiles way back in the 1930s, houses more than 1000 ceramic manufacturing units at present, and is known as the Ceramic capital of India.

With rapid urbanization in India and the emphasis on Smart Cities by the Indian Govt., the demand for ceramic tiles and sanitaryware is anticipated to grow rapidly till 2030. The growth in the Indian ceramics market is driven by the country pitching for infrastructure (metallurgical, cement, roads & bridges, buildings, etc.), energy generation (thermal power plants, hydrogen energy, solar energy, etc.), transportation (automotive, aerospace and railways) and strategic initiatives (indigenous production of defense equipment) which require technical & industrial ceramic components. According to a study by the US State Department, there is a large and growing middle class of more than 50 million Indians with a disposable annual income of more than Rs. 2.0 to Rs. 10.0 lakhs is expected to increase the growth in the ceramics market in India tenfold by 2025 due to the rising demand for high-quality infrastructure, transportation, and sustainable energy. *[Source: American Ceramic Society Bulletin, Vol. 91, No. 8, pp 35-44 (2012)].*

The majority of the Indian export of ceramic products are to the Middle East and Europe with Saudi Arabia accounting for up to 20% of the total ceramic exports.

The rising demands in the domestic and export market need to be met by suitable initiatives by the Indian industries for which a clear roadmap needs to be set.

Overview of Some Key Application Domains

The ceramics sector is important for industry across multiple fronts and domains. Application cover wide areas ranging from strategic areas namely defence, aerospace, atomic energy, etc. to industrially relevant areas such as construction, telecommunication, power, transportation, etc. to name a few. In terms of focus sectors, ceramics encompass healthcare, environment, energy, and so on.

Here we provide a broad overview of some key application areas that are catered to by various domains of ceramics namely traditional ceramics, refractories, advanced ceramics, composites, bio-ceramics, ceramic membranes, electro-ceramics, energy materials, and specialty glasses.

Traditional Ceramics and Refractories:

The traditional ceramics sector comprises tiles (roof tiles and floor tiles), bricks, sanitary wares, table wares, ornaments, glass wares, ceramic insulators, cement, and refractory bricks. Almost half of the market consists of sanitary warewith the other half being made up of 30% tiles and 20% tableware. This sector has the number of challenges, such as stringent environmental norms, the rising cost of production, high energy intensive and low-efficiency processing, etc. Kiln design, increased efficiency in firing, and energy-saving innovations and materials technology are being adopted worldwide to meet these challenges.

The availability of raw materials typifies the challenges for the refractories sector. Naturally occurring minerals like fire clay, kyanite, bauxite, sillimanite, magnesite, etc, and synthetic raw materials like alumina, mullite, magnesia, etc. are being routinely used in this sector. Non-availability of raw materials makes the Indian industry heavily dependent on foreign sources, particularly China. Magnesite is one such example; so is alumina-silicate, which has a high content of alumina. Beach sand minerals like sillimanite and zircon are used for the production of refractories. Graphite and non-oxide materials will be largely the future refractory materials for iron and steel plants. Monolithic refractories (castables, gunning mix, and plastics) are being increasingly used to enhance performance.

Advanced Ceramics and Composites

Advanced ceramics and ceramic matrix composites constitute an important segment of ceramic materials, especially for high-temperature structural and wear-resistant applications. They exhibit superior thermal (thermal shock resistance), mechanical (higher hardness and compressive strength), tribological (lower wear rate), and corrosion resistant properties both at ambient temperature and at high temperature and have lower density compared to high-temperature metallic alloys currently in use.

In this family, carbides, nitrides of silicon, aluminum, tungsten, etc., borides of titanium, zirconium, hafnium, etc., various oxycarbides, carbonitrides and oxynitrides (such as silicon oxycarbides, silicon carbonitrides, SiAlON, etc.), fibers of silicon carbide, silicon nitride and ceramic matrix composites made of carbon/SiC/Si3N4 fiber reinforced SiC/Si3N4 composites are of immense strategic importance for our country.

In the Indian context, there is a rising demand for the usage of advanced ceramics and composite materials for various strategic applications, such as high-speed missile radomes, bulletproof vehicular armor, nuclear power generation applications, etc. The technologies for processing these are strictly guarded by established foreign powers. Some technologies and products are under embargo. This makes it imperative to develop indigenous technologies, preferably with indigenous raw materials for processing and fabrication of these materials and components thereof.

In addition, advanced ceramics and composites are also finding a large array of engineering applications in automotive, aerospace, chemical, petrochemical, energy, iron &steel, and other material manufacturing sectors.

Rare Earths

Rare Earth are essential components that are used in small quantities to serve identified applications. Yb-doped high-power fiber laser of multi-kilowatt power is necessary for directed energy applications besides satellite lasers to be explored to clear space debris. Tm-doped glass is an important component to develop Directional Infrared Counter Measure (DIRCM) suitable for the anti-missile system, La-doped glass for making night vision goggles, Nd-doped bulk Laser glass for guidance system for national security, in the development of LiDAR system to monitor the strategically important territory. Er-doped glass is used for the fiber-based system for data transmission in a nuclear environment, Sm-dope system to make permanent magnet suitable for high-temperature operation, high-resolution telescope for use in space research, high-end electronics gadgets (smartphones, electronic panels), efficient LEDs, etc. Besides, all of the above applications, when combined with other strategically important materials, could be used to build highly efficient batteries, electrical cars for the next generation, and so on. Another area of current research interest in terms of strategic application is the requirement of Blue-Green lasers for underwater strategic areas to detect submersed substances, navigation, coastal security, etc.

Energy and Functional Materials

Glass and ceramics are key materials for the safe generation of non-conventional forms of energy. Affordable hydrogen generation is the basic pillar of the hydrogen economy, especially for the developing world. In 2021, the Government of India (GoI) announced the National Hydrogen Energy Mission (NHEM). In this context, the production of hydrogen using a high-temperature Solid Oxide Electrolyzer Cell (SOEC) has high potential due to its high efficiency and economy of scale. It is important to develop SOEC for sustainable power generation with solid oxide fuel cells (SOFC). It is important to indigenously develop such materials and components to catch up with the global demand for these cutting-edge technologies related to non-conventional energy generation and storage.

In terms of materials related to Li-ion battery technology, the primary raw materials required for cathode powder manufacturing, which makes 35% of a cell cost and 10% of total EV cost, are Manganese, Nickel, and Lithium.

For electrode powder manufacturing, access to appropriate mines for Lithium, Manganese, Nickel, etc. is thus required. Lithium is mainly controlled by three countries in the world: Australia, Chile, and Argentina. India does not have any definite source of Lithium. Whereas, the supply chain of Nickel is more fragmented and distributed in Brazil, Russia, South Africa, and Canada. Nickel is not produced from primary sources in the country and the entire demand is met through imports. Fortunately, India has manganese ore deposits that occur mainly as metamorphosed bedded sedimentary deposits associated with Gondite Series (Archaeans) of Madhya Pradesh (Balaghat, Chhindwara &Jhabua districts), Maharashtra (Bhandara & Nagpur districts), Gujarat (Panchmahal district), Odisha (Sundargarh district) and with Kodurite Series (Archaeans) of Odisha (Ganjam & Koraput districts) and Andhra Pradesh (Srikakulam& Visakhapatnam districts). It has been estimated that the production of manganese ore at 2,820 thousand tonnes during 2018-19 will be increased by about 8% as compared to that in the previous year (Source: Indian Bureau of Mines, GOI, 2017 report). The other alternatives to Li-ion batteries are highly needed. Presently, sodium-based, ceramic electrode based instead of liquid-based electrolyte batteries, and supercapacitors are being researched but are at the infancy stage.

Membranes

Ceramic micro and ultrafiltration membranes are niche products, though significantly costly compared to their polymeric counterparts. Membranes are considered excellent water treatment technologies as they operate without any chemical additives or thermal inputs.Regeneration of spent media is also not mandatory. Ceramic membranes are made of inorganic materials (such as alumina, titania, zirconia, silicon carbide, or some glassy materials). In contrast with polymeric membranes, they can be used in separations where aggressive media (acids, strong solvents) are present. They are amenable to high-temperature use because of their good thermal stability. On the application front, ceramic membranes find use in challenging water purification processes such as industrial effluents, oil-water separations, removal of heavy metals, gas separation and so on.

The Indian & Middle East ceramic membrane market is estimated to surpass US$ 1,687.20 million in terms of revenue by the end of 2028, exhibiting a CAGR of 10.20% during the forecast period (2021 to 2028).
[Source: https://www.coherentmarketinsights.com]

Specialty Glasses

The commercial glass market in India has already evolved from a small-scale, decentralized manufacturing business to a relatively organized marketplace. Now, it is rapidly expanding on account of emerging industrial infrastructure, specifically automotive and construction sectors, as India is one of the largest consumers of glass in construction around the globe. In addition, the use of

special glasses in the automotive sector is huge in near future.
The performance of glass manufacturing units is mainly dependent on energy consumption efficiency and the adoption of technological advancements. Increasing urbanization and an increase in disposable incomes of end users are predicted to drive the demand for the market on account of increased acceptance of green and sustainable architecture.

India commercial glass market is anticipated to witness significant opportunities and is estimated to grow at a CAGR of around 12% over the forecast period i.e., 2019-2027. India's commercial glass market is segmented by type and by industry.

Market Segmentation in glass comprises of Container Glass, Fiber Glass Float Glass, and Specialty Glass. Specialty glasses possess high mechanical strength with chemical resistance, and optical transmission. These glasses have huge applications in different fields such as lightening, engineering, electronics, optics, ophthalmic lenses, and glass-ceramics. If we consider specific product portfolios,

this includes lighting, cookware, flat-screen displays, fiber optics, and ophthalmic lenses. Specialty glasses with a suitable composition are used in strategic areas such as Lasers, space, and defense. Even though market demand in India is not known clearly but is strategic and technologies are guarded. Presently most of the components are imported. Hence, newer as well-established technologies must be developed for the self-dependent nation.

Optical Fibres

The global market for fiber optics is projected to grow at a CAGR of 10.9% during the period 2022-2027, during which time its quantum is expected to increase from $ 4.9 billion to $ 8.9 billion. The Asia Pacific is expected to occupy the highest share, with the communication application segment being the most dominant player.

Incidentally, this market is envisaged to be dominated by the glass segment, and the expansion of the segment is also projected to be higher than its plastics counterpart. This would primarily be due to the higher performance of glass fibers on almost all fronts namely corrosion resistance, temperature resilience, operating spectrum, and so on. Key drivers for the market include growing

penetration of the Internet, enhanced demand for bandwidth, and the explosive increase in data usage and transmission.
India currently has almost 28 lakhs kilometers of an optical fiber network that is slated to rise to 50 lakh kilometers by 2024, with an annual deployment rate of around 4 lakh kilometers. Despite this, only two Indian companies Sterlite Technologies Ltd., Aurangabad, Maharashtra, and Aksh Optifibre Ltd, Hyderabad are involved in making standard communication fiber for optical fiber cabling. Indian manufacturers produce 100 million kilometers of optical fiber annually, which falls short of the national requirement by almost 50%.

Apart from telecom, the Indian defense sector is currently procuring fiber-based laser components and fibers for gyroscopes and other uses. Low-quality imported fibers pose a serious challenge. Apart from this, Er/Yb co-doped specialty optical fibers and Yb doped fibers required for high power optical amplifiers and high power fiber lasers have been used for the satellite communication system, LIDAR application, metal cutting, marking engraving, etc. The availability of 99.9% silica is not there in India. All are imported presently at a very high cost.

Bio-ceramics and Healthcare Applications

Among different biomaterials used for the replacement and/or restoration of functions of natural tissues, bioceramics occupy a special place (compared to metals, polymers, and their composites) due to their unique characteristics and properties. For example, natural bone is a composite material consisting of CaP-based ceramic as the major constituent. As a result, hydroxyapatite bioceramic is still considered the gold standard for hard tissue replacement, which exhibits high bioactivity, bone-bonding ability, and osteogenesis. Similarly, bioinert ceramics such as Al2O3, and ZrO2 are very popular for load-bearing implant applications namely total hip replacement, and dental implants. Metals and polymers may not replace bio-ceramics for these applications in addition to applications where bioresorbability with sufficient mechanical strength is an additional requirement.

Globally the bioceramics market is expected to grow at a CAGR of 6.5% during (2021-2030)
(https://dataintelo.com/report/bioceramics-and-hydroxyapatite-market/).

The value of the global bioceramic market was US$ 19.3B in 2020 and is expected to reach US$ 26.7B by 2027
(https://www.strategyr.com/market-report-bioceramics-forecasts-global-industry-analysts-inc.asp).
Among different bio-ceramics categories, alumina appears to dominate the market with 4.1% CAGR and is estimated to reach US$ 13.3 B by 2027.

In terms of countries, US market is highest followed by China, Japan, Canada, Europe and Germany. The increasing trend of the ageing population and consequent increase in the risk of degenerative diseases like osteoarthritis, joint-related problems, trauma, and dental issues have fuelled this high growth trajectory by raising the demand for the production of the large number of implants and prosthetics.

Electro-ceramics and Sensor Applications

Electro-ceramics include piezoelectric materials, ferrites, solid electrolytes, multi-ferroics, and ferroelectrics. Sensor technologies are of pivotal importance because of the increased demand for physical, biological, and chemical recognition systems. Their applications range from environmental monitoring, medicine, medical diagnostics, healthcare and industrial manufacturing, food quality monitoring, defense, safety, and security. These sensors have also been widely used in automotive and aerospace applications. Metal oxide semiconductors (MOS) gas sensors also represent a major component of the sensor market.

The global Piezoelectric Ceramics market size was valued at USD 957.44 Million in 2021 and is expected to expand at a CAGR of 4.97% during the forecast period, reaching USD 1281.15 Million by 2027.

3.4 Bridging the Gap

Divergence in Global Supply Chains

India is having rich mineral reserves for basic raw materials such as china clay, fireclay, feldspar, quartz, bauxite, dolomite, alumina, mullite, magnesite, chromite, talc, wollastonite, calcite, gypsum, limestone, sillimanite, kyanite, titania, etc. which are used with minimum purification, beneficiation or other processing for traditional ceramic industry. However, the same cannot be said for the raw materials for the advanced ceramic industry. Advanced ceramics, such as silicon carbide, silicon nitride, zirconia, sialon, etc. require high purity raw material with controlled submicron size distribution and homogeneous distribution of dopants. For several of these raw materials, India is dependent on imports from China (e.g., lithium feldspar), Australia (e.g., spodumene), the USA (e.g., silicon), Germany (e.g., microsillica, high alumina refractory, etc). To meet emerging demands of advanced ceramics in the Indian market, such as bioceramics, nanoceramic powders, electronic grade ceramics, electrolytes for solid oxide fuel cells, lithium batteries, high-grade refractories, etc., India is heavily dependent on imports from China, Japan, Europe, and the USA. In some critical areas, such as ceramic matrix composites, India faces technology denial or embargo for ceramic fibers (such as high purity silica fibers, high strength carbon fibers, SiC fibers, etc.).

3.5 Focus Towards Sustainability

India intends to attain the status of a carbon-neutral economy within 2075. This target has been envisaged in fixing and revising intended nationally derived contribution (INDC) that focuses among others, on nurturing sustainable processes in industries. Ceramic industries, with particular reference to pottery and tiles, unfortunately, represent among the most polluting industries in terms of carbon emissions. In a study by European Union on emission sources from ceramic industrie 64% seem to come from fuel combustion; and process emissions and indirect emissions account for 17% and 19% respectively.

[Source: Ceramic Roadmap to 2050, www.cerameunie.eu]

It is pertinent therefore to ensure that the Indian ceramic industry adopts ways to reduce combustion-related emissions along with others. European Union has adopted such technologies e.g. microwave-assisted drying, heat pumps, use of biomass, biogas, syngas, green hydrogen, and electrification; to name a few. Indian ceramic clusters and industries has not enabled yet to use similar technologies and processes.

Additionally, it is felt that adoption of the following could also help in attaining carbon neutrality in a reasonable period:

- Less use of carbon-containing additives
- Use of optimized clay mixes in terms of carbon content
- Use of lesser quantity of raw materials for same use
- Adopt technologies for the removal of carbon and evolve other offsetting measures

3.6 Key Enablers

Some key enablers to address the gaps between national and global contexts; also to leverage the national capabilities, comprise multiple elements that range from technology, policies, infrastructure, and the R&D ecosystem. While some of them assume a more generic nature that cut across the various segments of the materials sector, some of them are highly differentiated sector-wise. We take a look at some of these enablers below and the challenges that are being faced.

- **Technology**

Technology by far constitutes the most crucial determinant in bridging the divide. Among the genetic elements associated with technology, some of the priority ones include the following:

1. **Upscaling the Value Chain:**
The technology value chain is characterized among others by readiness levels that provide the relative positioning of a given technology concerning others and also the market. Upscaling technologies from the laboratory level to the operational level constitutes a critical challenge that needs to be addressed. This inter alia includes institutional mechanisms to be put in place in the form of incubators, innovation parks, and so on.

2. **Upscaling the Value Chain:**
Technology Transfer Mechanisms: The transfer of technologies to appropriate users is key to adoption and absorption. Currently, the guidelines and ways ofsuch transfer are disparate and diverse; varying significantly among various providers. Seamless mechanisms for technology transfer and protocols thereof would be a strong enabler to driving an innovation ecosystem in the ceramic sector.

Among the sector-specific aspects, the following could be considered:

Advanced Ceramics & Composites:
In India, there is no indigenous technology for the fabrication of advanced ceramics fibers which are the essential ingredient for the production of ceramic matrix composites. Currently, India lacks indigenous technology for manufacturing controlled atmosphere high vacuum furnaces which are necessary for advanced ceramic synthesis and fabrication. Emerging technologies for the synthesis of green ceramic bodies by additive manufacturing need to be indigenously developed at an industrial scale.

Rare Earth Elements:
Important technological gaps exist in the effective use of by-products and also in the recycling of chemicals and e-wastes. Technologies need to be explored for the extraction of rare earth elements from such waste materials, including appropriate separation technologies. The ambit should also cover coal and coal ash.

Bio-Ceramics:
Current practice in bio-ceramics can be significantly improved in terms of their long-term stability, functional performance, and application potential through material/ technology innovations. For example, bioactive hydroxyapatite (the gold standard for bone replacement) suffers from low mechanical strength and inherent brittleness, which restricts its use as non-load-bearing implants or as a coating on load-bearing metallic implants. Some of the important areas in terms of materials/ technologies that India can contribute, leading to a unique market position, include knowledgebase/technologies for biomechanics, stable/ high toughness bioinert ceramics for total joint replacement, composite dental fillers, and enamels; injectable ceramic bone types of cement to address issues with current PMMA based bone cement, etc. Current bioactive ceramics are based on CaP only (HA, β-TCP, biphasic HA/TCP). Novel non-CaP-based bioactive ceramics are required to address the limitations of these traditional CaP ceramics in terms of their biological functions such as accelerated bone bonding, new bone formation, and osteogenesis leading defect healing. For load-bearing implants such as hip, knee, and spine, currently, Al_2O_3 and ZTA-based oxide ceramics are popular. However, newer materials based on non-oxide ceramics are required which have the potential to provide both mechanical, and tribological properties in addition to biological properties in terms of providing infection resistance. Multi-material ceramics that can mimic natural tissues in terms of composition and geometry leading to activation of natural biological activities and thus accelerated tissue healing/ regeneration is another domain that needs focus. Examples include electro-mechanically active composites.

- **Government Support**

Support from the government is of paramount importance to the various segments of the materials sector.
Initiatives need to be taken at the Government level to form a national-level advanced ceramics program with major emphasis on the indigenous development of raw materials and precursors for advanced ceramics & composites.
Government support, either centrally or through state governments, should be provided towards enhancing Rare earth extraction, exploration, manufacturing, and production in India. This should be synergized with support to private establishments to set up suitable infrastructure for technological development in REE sector and promote innovation and entrepreneurship.

For the bio-ceramics domain, the government should implement the Indian Certification of Medical Devices (ICMED) which was initiated in 2016. Apart from improving competitiveness, this would reduce the time required for international approvals.

Import duties and FDI need to be rationalized where the duty for finished implants happens to be lower than that of raw materials, thereby impeding manufacturing.

The imposition of anti-dumping duty on ceramic tableware and kitchenware imported from China is one of the major ways to prevent dumping in Indian markets. Incentives such as lowering of goods and service taxes for tiles, sanitary ware, and tableware produced by Indian manufacturers (which is already in practice) are a crucial driver for the industry

Government initiatives and schemes tailored for MSMEs that focus on cluster development, upgradation of technologies, and promotion of exports would be particularly beneficial.

- **Collaboration and R&D**

Networking with academic and R&D institutions in India and abroad; leveraging the strength of bilateral and multilateral international cooperation programs; promoting participative science and participatory technology development with industrial partners should be explored and implemented. Such linkages should be cut across sectoral barriers to avoid silos.

- **Capacity Building: Infrastructure and HR**

Center of Excellence (CoE) may be set up at a premier national institute with a proven track record of delivering products and solutions related to advanced ceramics & composite. Such centers should be equipped with the necessary infrastructure for innovative product and process development along with necessary training programs for skilling industry professionals from MSMEs/ Corporates.

- **Supply Chains and HR**

Availability of high purity raw materials and precursors for manufacturing advanced ceramics remains an issue of major concern. For example, high purity Silicon (purity higher than 99.999%), which is the starting material for electronic grade Silicon Carbide, Silicon Nitride, etc. is not available in India. Various polymer precursors and organo-metallics that can contribute to the green synthesis of advanced ceramics are also not produced in India. For various raw materials including dopants, India is dependent on imports from China, which needs to be curbed. Advanced high-grade ceramics fibers (SiC) which are a primary source of manufacturing CMCs are produced by a few global powers (eg., USA, Japan). These are not available for imports in large quantities for strategic usage. For achieving self-reliance, the above supply chain issues need to be addressed adequately.

For the energy sector too, many of the raw materials required for component/ system development are imported. Accordingly, emphasis should be given to developing globally competitive process lines/technologies for indigenization of the materials having properties at par with the global benchmark.

To encourage private companies as well as Indian R&D organizations in the field of Rare earth extraction, a strong supply chain is also essential and identifies the end-user industrial sector for the development of different types of products. From time to time, a survey is also necessary to identify newer applications of REE and inform the same suitable sectors (viz. Chemicals, Renewable Energy, Electronics System Design and Manufacturing (ESDM), and Electrical Mobility) for the initiation of the activity to ensure the domestic demand of REE.

India lacks many Industries which are essential to be in place for using the already developed technologies. Such as the advanced materials, high-end equipment and components, and sensor industry which is required in each sector for different applications. These must be developed through startups and many indigenous technologies can be translated through them which are at good progress stage and prototypes are demonstrated.

3.7 Way Forward

- **Addressing New Segments:**

India lacks many Industries which are essential to be in place for using the already developed technologies. Such as the advanced materials, high-end equipment and components, and sensor industry which is required in each sector for different applications. These must be developed through startups and many indigenous technologies can be translated through them which are at good progress stage and prototypes are demonstrated.

- **Developing Complementary Ecosystems:**

It has been found that despite industry demand, there are very few players in the area. Efforts should therefore be made to increase the number of participants to develop a competitive as well as a mutually complementing ecosystem. Government support should focus on facilitating the establishment of manufacturing bases in the domain.

Collaborations form an important route for complementing the ecosystem. Networking with academic and R&D institutions in India and abroad; leveraging the strength of bilateral and multilateral international cooperation programs; promoting participative science and participatory technology development with industrial partners should be explored and implemented. Such linkages should be cut across sectoral barriers to avoid silos.

- **Strengthening Supply Chains:**

Developing sustainable industries and industry clusters in various application domains of ceramics is instrumental in driving the supply chain. This should inter alia cover vendor development that would fast-track the manufacturing process through component development

The non availability of raw materials often serves as an impediment to industry growth and maturation. For example, electronic grade silicon carbide and silicon nitride are not available in India; or the raw materials for refractories are of poor grade. It is important to address such issues through either alternative sources or other technological interventions.

Ceramics clusters in the country also face an acute crisis of raw materials supply that has been seen as a critical impediment to growth. It is important to strengthen supply chains for raw materials in order to ensure the optimum functioning of the clusters.

- **Facilitating Techno-entrepreneurship:**

Facilitating techno-entrepreneurship in new ceramic materials development that is synergized through R&D and technology inputs from national laboratories, academic institutions, etc. could prove to be an important driver in sustaining a vibrant industrial base. Such an effort should act as a feeder line for the development of start-ups and indigenous manufacturing hubs in the country.

- **Enhancing Capacity:**

Setting up national centers for ceramics testing and characterization; setting up skill centers; implementing new curricula for university science and engineering programs; inculcating trans-disciplinary skills in management, entrepreneurship, etc. could form important components in capacity building for the sector. It is important to bolster the industry-academic-institute connection through the establishment of Centres of Excellence in identified areas within the premises of national-level R&D institutions.

- **Enabling Policies:**

Government should put in place enabling policies that encourage the use of indigenous raw materials and resources; the use of indigenously developed technologies; and an ecosystem that nurtures new MSMEs in the domain.

Policies and guidelines for setting up incubators in research institutions, innovation parks that are government owned and privately managed; and leveraging identified zones of the country as regional innovation systems should form essential components of the vision.

3.8 Chapter Contributors

On behalf of the CII National Mission for Technology, Innovation and Research, we would like to acknowledge and express gratitude to the following for their contributions in the Chapter on Ceramics:

- Dr Suman Mishra, FNASc Director, CSIR-Central Glass and Ceramic Research Institute
- Prof. Bikramjit Basu, Professor, Indian Institute of Science, Bangalore
- Dr. C D Madhusoodana, Additional General Manager, Ceramic Technology Institute
- Prof. Ravi Kumar N V, Head, Met. Mat. Engg., IIT Madras
- Mr Niraj P. Bhukhanwala, Director, Bhukhanvala Industries Pvt. Ltd
- Prof. Dr. Sanjay Mathur, University of Cologne, Germany and President, American Ceramic Society

CHAPTER 4:

RARE EARTHS

4.1 Material and its Background:

International Union of Pure and Applied Chemists (IUPAC) defines rare earths (RE) as a group of seventeen elements having atomic numbers 21 representing Scandium (Sc), 39 for Yttrium (Y) and Lanthanum (La) having atomic number 57 to Lutetium (Lu) of atomic number 71. These elements have similar chemical properties and are placed in group III of the modern periodic table (Fig.4.1.1).

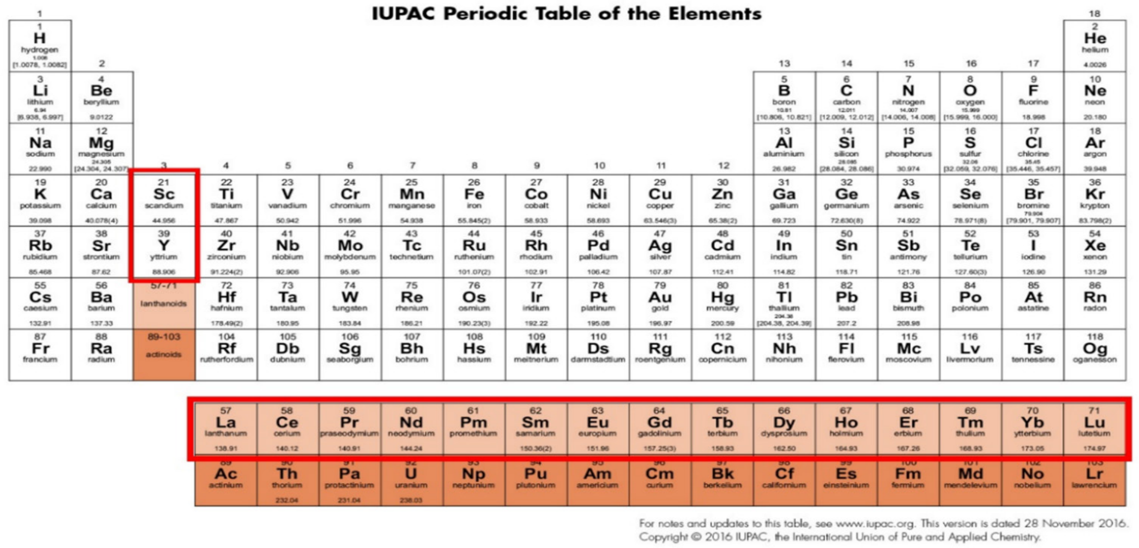

Figure 4.1.1. Periodic table of elements showing rare earth elements

The term 'Lanthanides' is used to represent the group of REEs having atomic numbers 57 to 71. It is named after the first element lanthanum of the group. REEs are commonly classified as light rare earths elements (LREE) and heavy rare earth elements (HREE) based on further similarities in their chemical properties of basicity, which is a measure of the ease with which the element can absorb hydrogen ions in aqueous solution and neutralise acid. HREE precipitate early at comparatively lower pH than LREE from solutions of mixed rare earth elements in mineral acids. LREE comprises of elements such as lanthanum (La), cerium (Ce), praseodymium (Pr) and neodymium (Nd) having atomic numbers 57, 58, 59 and 60 respectively. Elements having atomic numbers 61 to 71 (promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Eb), thulium (Tm), ytterbium (Yb) and lutetium (Lu)) along with scandium and yttrium are grouped under HREE.
LREE are also known as 'Cerics' named after the element cerium, which is most abundant in that group. HREE are named 'Yttrics' after yttrium (Y), representing most dominant element of that group. Rare earth element Promethium (Pm)

having atomic number 61 does not have any stable natural isotope and hence it is not available from mineral sources for commercial applications. This element is obtained by processing of spent fuels discharged from nuclear reactors.

4.2 Key Market Segments – Current and the Evolving Market Segments

Unique atomic structure of REEs endow them with special performance enhancing phosphor, optical, electrical, magnetic, chemical and metallurgical properties making their use essential in various cutting-edge applications of strategic sectors as well as in various high technology products of common civilian usages of significant economic importance.

4.3 Rare Earth Applications

- **Applications in strategic sectors:**

1. Rare earth permanent magnets (REPM) having high specific energy products, which can retain high force of magnetisation in temperatures as high as 5000C (special samarium cobalt magnets) are used in drive motors of missiles and 'Smart' bombs under the category of 'Precision guided munitions" (PGM).
2. Travelling wave tubes (TWT)(1) used in many space (satellites in orbit communicating with earth station) and military applications (RADAR communications with missiles and air crafts) needing communications over long distances, use REPM, designed and made to close tolerances and maintain field strengths in the harsh environmental operating conditions of space, for amplifications of the generated signals.
3. Neodymium: Yttrium Aluminium garnet LASERS are used as range finders, target designators and target interrogators.
4. Samarium Cobalt (SmCo) or neodymium iron boron (NIB) permanent magnets and terbium iron nickel alloy with dysprosium (Terfenol-D) are used in stealth technology in helicopters.
5. Noise level of helicopter rotary blades is measured and with help of computer systems Tefenol-D actuators are driven to create equal and opposite force of equal frequency but 180 degree opposite phase for cancelling the noise.
6. SmCo permanent magnets are used in the electrical generation systems of the aircrafts. Compact actuators made of high-power rare-earth magnets are used to move flaps, rudders and ailerons for flight control.
7. Yttria stabilised zirconia is used as thermal protection coating of the high-speed jet engines.
8. Europium and terbium rare earth phosphors are used in the display panels of the cockpit in the aircrafts.
9. Under water mine detection system uses Neodymium: Yttrium Aluminium garnet LASER to scan underneath water from an airborne source.

- **Applications in non-strategic sectors**

1. Industrial applications of rare earths in non-strategic sectors far outweighs those in strategic sector in terms of volume.
2. Cerium is used in manufacture of catalysts of fluid catalytic cracking (FCC) process in petroleum refineries for producing high octane number gasoline that does not necessitate addition of octane boosting agents considered carcinogen when combusted in automobile engines. Cerium compounds are also used in the catalytic converters of automobile exhaust system for control of harmful NOx and carbon monoxide emissions.
3. Cerium, lanthanum along with neodymium are used in the production of mischmetal used for making nickel metal hydride (NiMH) batteries for storing electrical energy. Cerium lanthanum mischmetal alloys are also used in ferrous and nonferrous metal industries as alloying element for control of grain refinedness of cast products improving their mechanical strength as well as resistance to corrosion.
4. Neodymium iron boron (NIB) high energy product permanent magnets are used in wind turbines for generation of wind electrical power with improved energy efficiency. NIB magnets are also finding applications in the drive motors of electric vehicles, superpower efficiency electrical motors (IE4 specification) used in various industrial, household, medical equipment and agricultural applications.
5. Rare earth LASERS find usage in digital communications and optical fibre transmission systems and variety of medical applications in precision surgery. Energy efficient fluorescent lamps, light emitting diodes, display screens of colour television, computers, smart phones have europium and terbium rare earth phosphors.
6. Rare earth usage has become essential in various high technology equipment and gadgets pertaining to multitude of industry sectors such as energy, environmental science & climate change, health care, information & communication technology, manufacturing, healthcare as well as security & defense.

Table1 below presents a summary of uses of REEs in emerging important industry sectors. A list of processes, components, equipment and gadgets is also presented alongside to emphasize that the point that development of REEs downstream value addition industries is diverse and to a large extent is dependent on the establishment and proliferation of their user industries' ecosystem.
To elucidate the problem high efficiency rare earth based permanent magnet motors need appropriate power supply and control system electronics for their normal operation. Any disruption in supply chain threatening the availability of semiconductor chips is a threat to successful industrial applications of these motors in end use equipment such as electric vehicle.

Table 1. Major applications of the rare-earth elements in emerging high-technology industries

(1) Catalysts: La, Ce, Nd, Pr, Lu, Y, Sm
Automotive catalysts Petroleum refining, fuel catalytic cracking, ethane polymerisation Fuel and hybrids, diesel fuel additive Air pollution controls, water filtration, hydrogen storage, flints
(2) Permanent and ceramic magnets: Nd, Pr, Sm, Dy, Tb, Tm, La, Ce
Cars—hybrids-plug-in and electric vehicles, window motors, screen wipers, starter motors, hybrid batteries, alternators, brakes Electronics—computer disc drives, data storage, iPods, DVDs, CDs, video recorders, consoles, video cameras, mobile phones Speakers, headphones, microphones, ceramic capacitors Wind-, hydro-, and tidal-power turbines
(3) Energy storage: La, Ce, Pr, Nd, Pm
Rechargeable NiMH batteries, battery electrodes, nuclear batteries, Hydrogen storage alloys for safe storage and transport of hydrogen.
(4) Metallurgy: Ce, La, Nd, Pr, Y, Sc, Er
Mischmetal in cast iron products for grain refinedness improves strength Cerium alloys of aluminum cast products improves creep at high temperature Nd, Pr addition in magnesium alloys improves corrosion resistance for bone prosthetics usage and other light weight structural applications. Sc alloy of aluminum has higher strength with improved creep and fatigue resistance Er alloyed with Vanadium lowers hardness and improves workability
(5) Phosphors: Y, Eu, Tb, Gd, Ce, La, Dy, Pr, Sc
LCD televisions and monitors, plasma televisions and displays, mobile phone displays Energy efficient fluorescent lights, high-intensity lighting, LEDs, mercury-vapour lamps Phosphors—red (Eu), blue (Eu), and green (Tb)
(6) Polishing powders: Ce, La, Pr
Television and computer screens—plasma, CRT Precision optical lenses and electronic components Silica wafers and chips, catalyst for self-cleaning ovens
(7) Glass additives: Ce, Er, Gd, Tb, La, Nd, Yb, Pm
CRT screens to stabilise glass from cathode ray Glass—optical lenses, glass for digital cameras, tinted glass, UV-resistant glass, high-refractive index glass, fibre optics
(8) Ceramics: Dy, Er, Ce, Pr, Nd, Gd, Ho, La
Colours in ceramics and glass —yellow (Ce), green (Pr), and violet (Nd)
(9) Medical equipment: various REE
MRI machines, X-ray imaging Surgical drills and tools, surgical lasers Electron beam tubes, computed tomography, neutron capture
(10) Other applications: Ce, Nd, Pr, Sm, Eu, Gd, Y, Dy, Tb, Yb, Er, Ho, Lu, Sc
Lasers (Yb, Y, Dy, Tb, Eu, Sm, Nd, Pr, Gd, Ho, Er), Superconductors (Gd, Y), Nuclear (Ce as additive in radiation resistance glasses, Gd, Eu & Er as neutron poison used to control nuclear reaction in reactors), Fertilisers (various REE), High-technology alloys (Yb, Lu, Er, Tb, Gd, Eu, Sm, Nd, Pr, Ho, Sc) Other applications may have futuristic functions, such as high-temperature superconductivity.

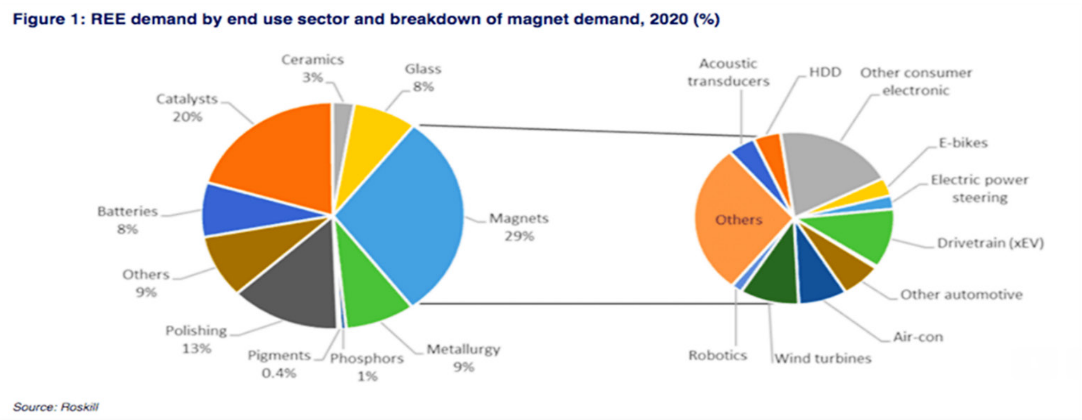

Fig.4.3.1 Presents applications of REEs in various industry sectors driving their demand

About 50% of total rare earth oxide is converted to metals and alloys for applications in metallurgical industries, production of nickel metal hydride batteries and high energy product permanent magnets. Roskill in their recently published report has stated that rare earth permanent magnet has emerged as a single largest end use of the rare earth oxide accounting for total 29% of rare earth oxides in 2020. Cerium and lanthanum are also used in certain product varieties of ferrite permanent magnets resulting in improvements of their magnetic properties and performance. This sector consumes neodymium, praseodymium, dysprosium along with cerium and gadolinium as fillers. Published patents also indicate possible use of lanthanum and terbium in the manufacture of rare earth magnets. Industrial applications of rare earth magnets are expected to grow, driven by its large scale applications in emerging market sectors such as electric vehicles, wind turbines for generation of renewable electricity, drones and robotics. As per forecast made by Roskill the year over year growth in REPM market will account for about 40% global rare earth oxide in 2030(2).

4.4 Strategical Importance of Material for India

India's GDP in 2021 is estimated to be 3.17 trillion (3) at current US$ and it contributes to 3.3% of that of the world. The country is expected to register a compounded annual growth rate of 7 to 8% during the period 2022 to 2030 and is projected to emerge among the top 3 largest economies of the world.

India is also committed for reducing its emissions intensity per unit GDP by 33 to 35 per cent below 2005 by 2030. Adoption of energy conservation measures in various industrial, commercial as well as residential establishments, implementation of alternative mode of transport that inter alia includes electric vehicles, biofuels and enhanced penetration of renewable energy etc. have become mandatory for weaning the country away from the current state of 100% dependence on fossil fuel-based energy system.
As per the NITI Aayog's forecast, nearly 80 per cent of the two- and three-wheelers, 40 per cent of buses and 30-70 per cent of the cars will run on electricity by 2030. India's transition to the electric mobility system can save Rs 20 lakh crore by 2030 on oil imports alone.

As can be seen from above, rare earths play a significant role in various strategic applications the technology of which may be hard to access, and country has been making steady progress in indigenously developing them in the field of space, atomic energy and defence. The country also needs to acquire necessary expertise and master the state-of-the-art technologies for using rare earths effectively in various emerging industrial applications that not only promotes energy efficiency but contributes to proliferation of renewable energy-based systems for achieving both the climate and economic goals. Realising the problems of sudden supply chain disruptions of many essential materials such as food grains, medicines, semiconductor chips etc. caused during the COVID19 pandemic as well as the evolving geo-political scenario, Government of India has launched a series of measures for boosting indigenisation of defence equipment, arms and ammunitions, electronic gadgets under its flagship 'Atmanirbhar Bharat" programme.

In view of above, rare earths and technologies for processing and converting them to relevant components in an economically competitive manner for the end user industries are essential for securing the future economic growth of India as well as sustainability of its strategic sectors from the point of view of its national security.

4.5 Market Size (in terms of volume and money) both Current and Projected for 2030

World production of total rare earth oxides is reported to be 2,80,000 ton in 2021 (4) Out of above the productions of Yttrium and scandium oxides are noted to be in the ranges of 8000 to 12000 ton and 10 to 25 ton respectively. Global market REEs is valued at an estimated 5.3 billion US$ (5) in 2021 and it is expected to grow at compounded annual rate of 12.3% till 2026.

Size of the REE market and volume of annual production though miniscule compared to those of major base metals such as iron, aluminium, coper etc., the contributions of REEs to overall world economy is seen to be more than 1000 times their market value. Production of total rare earth oxides in India was 2900 ton in the same year.

Detailed break up of productions of LREE and HREE is not available and can be inferred from their consumption trend. LREE accounts for about 90% of total consumption of rare earths and remaining 10% of consumed rare earths are HREE. Yttrium contributes to about two third of total consumption quantities of HREE whereas cerium and lanthanum together account for about 75% of LREE consumption by volume. In value terms only four rare earth elements such as neodymium, praseodymium, dysprosium and terbium contribute to more than 90% of the total consumption of all rare earths. These four rare earth elements are used in production of high energy product rare earth permanent magnets, which is finding increasing applications in the wind turbine generators for renewable energy production, energy efficient electrical drive motors of electrical vehicles, drones, industrial automation systems, robots etc. The market for Nd, Pr, Dy and Tb industry applications is growing and there is a concern of supply of these rare earth elements failing to catch up with their demand.

Only eleven rare earths such as cerium, lanthanum, neodymium, praseodymium, samarium, europium, gadolinium, dysprosium, terbium, yttrium and erbium largely cater to the industry demand of high technology applications for manufacture of products of mass consumption whereas the remaining rare earth elements are used in multitude of niche strategic applications such as aerospace and defence industries.

Table 2. Mine production of rare earths in 2021 (Equivalent REO, Ton)

Table 2. Mine production of rare earths in 2021 (Equivalent REO, Ton)

Country	Quantity	Remarks
China	168000	85% of global rare earth refining is done in China
USA	43000	Entire quantity mined by MOLYCORP is sent to China for refining
Burma	26000	Entire quantity is sent to China for refining
Australia	22000	Mined quantity is refined in Malaysia in the facility of LYNAS
Thailand	8000	-
Madagascar	3200	-
India	2900	IREL has in house RE extraction and refining facility. Under inter Government agreement subsidiary of a Japanese company has also set up refining capacity in India to refine mixed rare earth chloride sourced from IREL.
Russia	2700	-
Brazil	500	-
Vietnam	400	-
Burundi	100	-
Other countries	300	-
World	277100	Silmet, Estonia and Treibacher, Austria also has small rare earth refining facilities

4.6 Rare Earth Industry in China

China has set up industries catering to entire value chain of rare earths starting from mines to electrical motor. Export of rare earth started in early 1980s from Chinese mines and by mid 1990s China has captured 97% of global production of rare earths from mines. Rest of the world closed down their mining and processing facilities of rare earth owing to lack of competitiveness of their rare earth products against Chinese supply. China has become net importer of rare earth ores and concentrates from 2018 onwards and actively pursues a government led policy to promote export of rare earth based final products highest in economic value chain discouraging those rare earth products lower in the economic value system. 2010 rare earth supply embargo by China alerted the world to the supply chain vulnerability of rare earth materials. Prices of refined rare earth oxides and compounds jumped more than 100 times and the global industrial users, countries undertook various steps to minimise, replace and recycle rare earths in their products and industries. The prices of refined REOs have come down after December 2011 and rare earth mine head production facilities have opened in various parts of the world. As a result, China's share of global mine head production of REO in 2021 has gradually come down to 60%.

In January 2022, China said it was creating a new state-owned enterprise (6), China Rare Earth Group, a 'megafirm' that will control 60–70% of the country's rare earth production, which amounts to 30–40% of global supply. China is also introducing new environmental standards for the industry, which could constrain supply. Six state owned Chinese companies i.e., China Minmetals, Chinalco, China Northern Rare Earth, China Southern Rare Earth, Guangdong Rare Earth and Xiamen Tungsten (Golden Dragon Rare Earth) have been assigned the job of consolidating the rare earth mining and mine head production of REO by acquiring and amalgamating all other operating units.

4.7 Indian Value Chain V/S Global Value Chain

- **RE resources in India**
  Indian deposits of rare earth metal is estimated to be 12.47 million tons of monazite (7) containing 55 to 60% total rare earth oxide. Atomic Minerals Directorate of Exploration and Research (AMD), a constituent unit of the Department of Atomic Energy (DAE), Government of India carries out explorations to augment resources of REE in several potential geological domains of the country. As on January 2020 AMD established 12.47 million tons of monazite containing 55-60% total rare earth element oxide in the coastal and

inland placer sands of the country. This amounts to 68,58,500 ton (say 7 million ton) of REO from monazite resources established by AMD in the country. In addition, AMD has estimated 3,46,462-ton REO (inferred category at 0.5% cut off) at Ambadongar area, Chhota Udepur district, Gujarat.

The coastal regions of the country are densely populated. Monazite is associated with other beach sand heavy minerals such as ilmenite, leucoxene, rutile, zircon, garnet and sillimanite which are also of economic importance. Monazite is produced as by-product of heavy mineral beach sand mining and mineral separation plant. Hence the available reserves of rare earth from monazite resources established by AMD is expected to be significantly lower than the above mentioned resource figure of 7 million ton REO.

Table 3. Rare earth reserves held by various companies with those in India from monazite

Table 3. Rare earth reserves held by various companies with those in India from monazite

Company, Country	Source mineral	Reserves (million-ton REO)
Baiyunebo, Baotau Steel Rare earth group, China	Bastnaesite	44.0
Maoniuping, Sichuan Province, Jianxi Copper, China	Bastnaesite	1.60
Mount Weld, LYNAS Corporation, Australia	Monazite rock	1.40
Zandcopsdrift, South Africa	Carbonatite	1.00
India	Monazite placer	7.00 (resource)–reserve estimate to be ascertained

- **Rare earth production and refining in India**

IREL operates beach sand heavy mineral mines in the states of Tamil Nadu, Kerala and Odisha and produces monazite. Odisha Sand Complex unit of IREL has a 10000 ton per annum (TPA) monazite processing plant for producing 11000 TPA mixed rare earth chloride equivalent to 5500 TPA equivalent REO. Under an Inter Government MOU between India and Government of Japan IREL supplies 50% of its production of mixed rare earth chloride to a wholly owned subsidiary of a Japanese company.

The India entity has set up a rare earth refining unit based on solvent extraction process at Andhra Pradesh to produce separated rare earth products of > 99% elemental purity. IREL also operates its own rare earth refining facility based on indigenously developed process at Rare Earths Division, Udyogmandal, Aluva, Kerala.

- **Downstream RE value added industries in India**

1. Catalysts: India has domestic catalyst production units owned and operated by private entrepreneurs. During the past years Indian Oil Corporation (IOC) has developed its proprietary INDMAXTM process licenced by Lummus company.

Bharat Petroleum Chemicals Limited (BPCL) has developed process know how to produce superabsorbent polymers SAP) and is setting up its out-production unit based on pilot plant result.

BASF holds its proprietary process know how for production of super absorbent polymers and the process uses cerium-based catalyst.

A few Indian processors in private sector have processing units to recover rare earths from spent FCC catalysts and they operated their plant during 2011 for meeting the requirement of their overseas customers when the rare earth prices skyrocketed following Chinese embargo on RE supplies to Japan.

2., REPM: Permanent magnet industries in India are at least 40 years old. Indian producers in private sectors produce AlNiCo and ferrite permanent magnets and cater to their customers. After introduction of REPM many of them have taken up the role of intermediary processors of REPM magnets sourced from China for catering to domestic as well as overseas customers.

Based on a published report, till 31st July 2021, there were 380 electric vehicle manufacturers (8) in India. With the increasing adoption of electric vehicles in the landscape, this number is only expected to increase further. The electric motor production units in India are well established and many of them manufacture super premium efficiency (IE4) electrical motors using imported REPM based rotors.

2. Metallurgy: Indian metallurgical industry is well developed. Rare earths mischmetal for applications in ferrous and non-ferrous industries are imported.

3. LASERS: As per a published report India has a 5% share of the global laser market with a history that dates back to 1992. In recent years, India has developed laser weapons and the DRDO has already tested a 1kW laser weapon system mounted on a truck.

Although India has many commercial manufacturers of lasers, India still does not grow the crystals in-house for commercial purposes. R&D in India in lasers is quite developed with strong efforts from the Solid-State Physics Laboratory in the DRDO, BARC, IISc, Raja Ramana Centre for Advanced Technology, DSC and IITK. All of these facilities have been able to grow Nd:YAG crystals in-house (amongst other crystals) and develop laser systems from these crystal rods. BARC has also developed Nd:glass lasers. The capability of numerous research institutions in India to develop laser systems hints at some collaboration between them, yet this appears to be limited to small-scale development efforts.

4. Glass & ceramics: Rare earth based ceramic colours are manufactured by a few Indian entrepreneurs and some manufacturers of ceramic wares use them in coloring the ceramic wares.

5. Glass polishing: This is a very old industry sector in India. Mixed RE oxide was earlier used to polish spectacle glasses, CRT display screens of televisions etc. After 2010 an entrepreneur has set up manufacturing unit of special cerium oxide polishing powder for polishing of solar photo voltaic cells.

4.8 Gap Areas

Rare earths' downstream application industry sector is varied. An important gap area is lack of industry standard technology know how for producing RE metals from REOs. This needs to be developed in the country as the possibility of accessing this technology from the established overseas industry players is remote.

4.9 Recommendations

- **Collaboration between industry, academia, research labs and startups:**

  National laboratories such as Bhabha Atomic Research Center, Defense Metallurgical Research laboratory, laboratories of Council of Scientific and Industrial Research such as Institute of Minerals and Metals Technology, National Metallurgical Laboratories are working on developing technologies to produce RE metal and production technology of REPM using indigenously available REO, sourced from IREL. Government intervention can catalyze the ongoing process and accelerate result delivery. Government can identify one of the RE based application industry sector for focused development of state-of-the-art technology bringing together industries, academic and R & D institutions.

- **To focus we can pick priority 5 materials:**

  Suggested technology sectors for developing REE downstream value addition industries in India can be rare earth permanent magnet, battery, metallurgy, catalyst, ceramics. These sectors along with usages in strategic sectors such as aerospace & defense and atomic energy account for about 70% of the global demand of REEs by volume.

- **Promote domestic production of REE downstream products:**
  At present import of REE compounds, metals and alloys to India are not significant. In certain sectors there may not be any data to show import. However high technology products using REEs in various forms are imported such as drive systems of washing machines, air conditioners, energy efficient motor rotors, display screens of TVs, mobile phones, computers, laptops, hard disk drives etc. Hence to reduce India's import reliance on REEs the country needs to promote domestic production units of REE downstream value-added products.

- **Government support:**
  Government may consider formulating suitable schemes for incentivizing and promoting domestic manufacture of REPM and rare earth metal, the effectiveness of such schemes warrants careful examination, keeping in view the diverse nature of industrial uses of these products and size of their overall market.

- State of the art economically competitive REPM manufacturing facilities inter alia including the process of making RE metals from their compounds is not available for adoption. Such technologies are closely held by a few oversees companies and not available for licensing for domestic production. Government can bring in appropriate policies for encouraging private sector in industries as well as private academic institutions for collaboration with various Government laboratories working on the development of such technologies such as CSIR laboratories, DMRL and BARC for accelerating the develop of technologies so that commercial scale production plants can be set up.

- Simultaneously, Government can leverage its diplomatic relations with appropriate countries to access the technology, if possible, for setting up REPM manufacturing facility in the country.

- Government can also encourage Indian entities to own overseas REE mines for augmenting supplies of HREEs to support such domestic manufacturing industries. Of late it is noted that many Indian private companies with the collaboration of their overseas technology partners have initiated lithium-ion battery production plants in the country in spite of the fact that India does not have any natural resource of lithium for commercial scale mining operation.

- Government of India has recently sought public opinion for opening of beach sand mineral sector to participation of private sector and appropriate legislative provisions may be introduced in due course for participation of private enterprises in heavy mineral beach sand sector.

- **Greater involvement of private sector in REE production:** Monazite is the only commercially important source of REEs in India at present. Indian monazite contains about 9% thorium oxide and some minor quantities of uranium. Monazite is radioactive and considered a source material for nuclear energy applications. REE extraction from monazite is accompanied by production of Thorium which needs to be stored in a safe retrievable form for use in in future atomic power programme of the country. It is a prescribed substance notified under the Atomic Energy Act 1962. At present handling and processing of monazite is only restricted to the Government sector.

- Monazite is a byproduct of the heavy minerals beach sand mining and mineral separation industry. Beach sand mineral industry was opened for private sector participation in 1998 making it free from Government monopoly. In March 2015 after amendment of the Minerals and Mines Development and Regulations Act, 1955 rules for Atomic minerals conservation and regulations as well as atomic minerals concessions were notified and the beach sand mineral sector was brought back under government control completely banning participation of private sector.

- Private sector participation in REE's refining operation and further downstream value addition technology applications is not a controlled activity and industries can be set up as per prescribed norms of chemical, metallurgical and manufacturing industries. At least two companies in private sector are known to be active in this business. Further purification of REE compounds and chemicals for removing non rare earth impurities to make it suitable for various pharmaceutical, and chemical applications is well established in India. Conversion of REO to metals and then on to alloys for magnetic and metallurgical applications is lacking to complete the REE economic value chain in the country. This missing technologically important processing activity in industrial scale is also necessary for in house recycle of swarf, generated by end stage machining of REPM blocks prior to their final assembly in various components.

- Recycle and recovery of electronic wastes in the country is also being prioritised by the Government. Participation of private enterprise in defence manufacturing and export of defence equipment, domestic manufacture of drones, robots for applications in security, surveillance, defence, agriculture and various other sectors are creating scope and promoting conducive industrial environment for setting up downstream value-added industries including REPM and other rare earth-based products of economic importance.

- REPM manufacturing industry and REE applications in technology sectors such as catalysts, ceramic, metallurgy, battery and hydrogen alloy storage etc. are rapidly evolving and getting closely integrated with relevant manufacturing technologies and process leading to their end applications. Hence successful long term competitive proliferation of these industry sectors depends greatly on the level of collaboration / feed backs and support they can avail from R & D institutions engaged in inventing new application products and industries striving to deliver customer value by enhancing product performance at reasonable cost. World over efs are on to reduce dependence on REEs, substitute them with non-REEs available abundantly in nature and recycle REES from the products at the end of their life. Hence appropriate R & D investment by concerned private sector investors is essential. Government policy on this direction can definitely be a booster.

4.10 Chapter Contributions

On behalf of the CII National Mission for Technology, Innovation and Research, we would like to acknowledge and express gratitude to the following for their contributions in the Chapter on Rare Earth:

- Dr R N Patra, Former CMD, Indian Rare Earths Limited (IREL)
- Prof. Suddhasatwa Basu, Director, CSIR-IMMT, Bhubaneswar
- Prof. Amol Gokhale, IIT- Mumbai
- Prof. Prodip Sen, IIT – Kharagpur
- Dr MLP Reddy, Secretary, Rare Earth Association of India
- Dr. M. Manivel Raja, Scientist-G, Head, Advanced Magnetics Group Defence Metallurgical Research Laboratory DRDO, Ministry of Defence
- Ms. Pallavi Gill, Exec.Director, RCMPA Polishing Tech.Pvt.Ltd.
- Mr Sagar Singh, Deputy Director & Scientist C, Bureau of Indian Standards

4.11 References

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CHAPTER 5:

BIO-MATERIALS AND IMPLANTS

5.1 Materials and its Background:

Biomaterials are a class of materials that may be natural or synthetic and are used in in vivo medical applications to support, enhance, or replace damaged tissue or a biological function. Biomaterials can be metallic, polymeric, and ceramic based products. The advanced materials in the field of biomaterials have been listed out. These materials include well defined and gold standard materials like UHMWPE, Stainless steel, Co-Cr alloy, Ti alloy and Zirconia which occupies a large share of implant market. Some of the other lesser used material (as compared to the above listed material) but of significant importance are β- TCP, hydroxyapatite, gelatin, collagen, PLLA, PLGA, PEEK etc. For instance, some of the industries where hydroxyapatite is extensively used are biomedical sector, food/fodder industry, pharmaceuticals, cosmetics, basic and advanced research laboratories. The focus of this national task force will be directed towards the development and utilization of the following advanced materials as biomaterials for indigenous biomaterial and implant development.

- **Advanced materials**: Phase pure and Thermal sprayed hydroxyapatite, β- TCP, Gelatin & Collagen, UHMWPE, PLA, PGA, PEEK, Bioactive glass (45S5), Poticon (Potassium Titanate), Zirconia, Alumina, Zirconia toughened alumina (ZTA)
- **Metallic biomaterials**: Stainless steel (different variations); Titanium alloy; Co-Cr-Mo alloy (F-75 grade), Nitinol (Ni-Ti shape memory alloy); Magnesium alloys.

5.2 Strategical Importance of Material for India

India has world's second largest population count, with the total number soaring 1.4 billion. As per the population census numbers by Govt. of India, the elderly population were close to 100 million in 2011 which increased to 140 million in 2021 and is expected to reach approximately 200 million by 2031. According to an UN report, India, projected to surpass China as the world's most populous country around 2027, is expected to add nearly 273 million people between now and 2050 and will remain the most populated country through the end of the current century **(Figure 5.2.1)**. Such high numbers clearly establish the need for improvement in healthcare sector, with the need for indigenous implants for the Indian population.

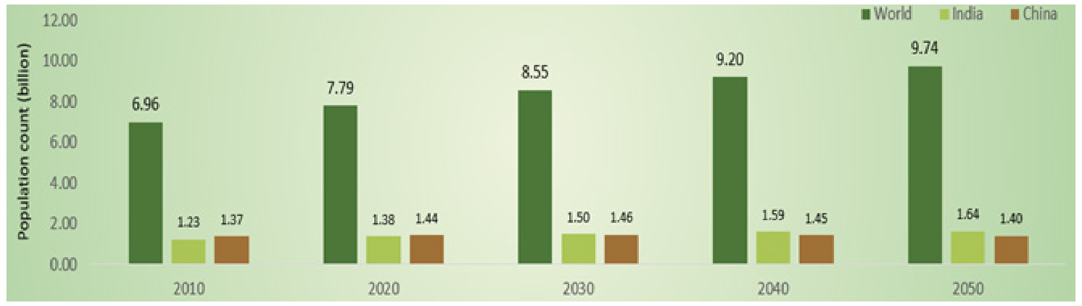

Figure 5.2.1: World population prediction and India's share in world population count. (Ref: Population Division of the UN Department of Economic and Social Affairs, Economic Times).

Almost, 80% of the implants used in hospitals/clinics are imported into the country, which make the healthcare treatment costly. More importantly, those implants do not suit Indian anatomy as the imported implant design is for western population (Dang et al.: doi.org/10.1016/j.vhri.2018.06.004). An Indian market survey report by Frost & Sullivan depicts overdependence of imports for sophisticated level of technology viz. cardiovascular stents, imaging techniques etc. **(Figure 5.2.2)**.

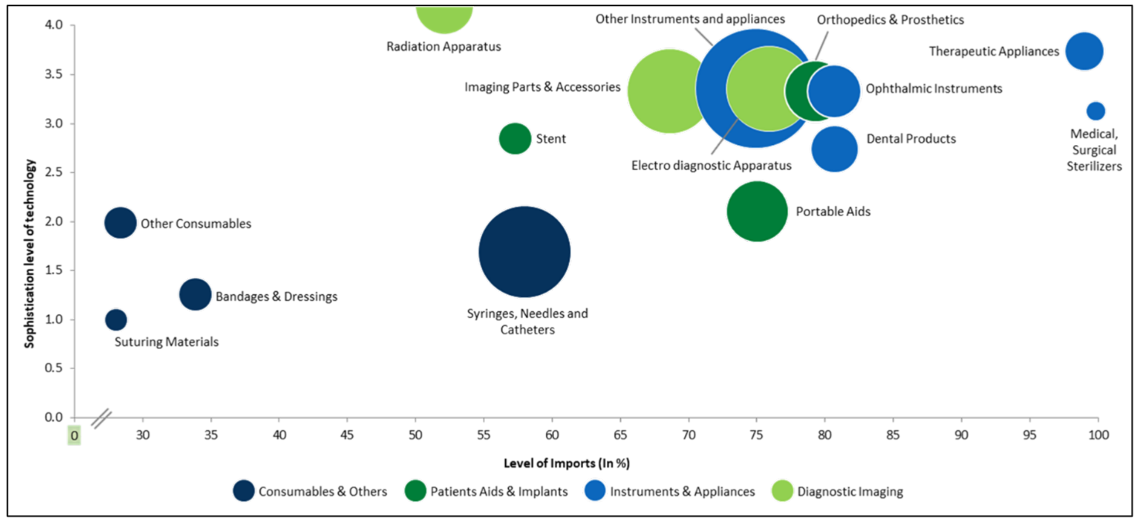

Figure 5.2.2: Level of Indian market imports of medical devices based on level of sophistication of the technology (Ref: Frost & Sullivan: Outlook of India's healthcare industry)

Significant focus on developing the raw material/resins for these advanced materials is also necessary, as the current scenario is over dependence on foreign supplier. The main disadvantage is higher cost, increased lead time and in several cases non availability of raw material for the Indian manufacturers.
Hence, an interdisciplinary translational ecosystem needs to be developed, where such advanced materials can be developed and can be further utilized for implant manufacturing for the Indian population at an affordable cost.

5.3 Global Value Chain

- Key producers and their volumes & financials:
  Some of the key players in biomaterials and implant development business are as following:

S.No	Company Name	Country	Approximate worth (Billion USD in 2021)
1	Medtronics	USA	30.12
2	Johnson & Johnson	USA	22.95
3	Abbott	USA	22.5
4	Philips	Netherland	19.32
5	GE healthcare	USA	18.01
6	BD	USA	17.1
7	Siemens healthcare	Germany	16.9
8	Stryker	USA	14.3
9	Boston Scientific	USA	9.9
10	Zimmer Biomet	USA	7.03

5.4 Indian Scenario

In India, 30% of the total healthcare expenditure is public spending, compared to 48.3% for the USA. Just 1.4% of the GDP is spent on public healthcare in India, compared to 8.3% for the USA. India needs to increase its public healthcare expenditure. Considering that public healthcare is often the only recourse for the rural and poor population, the public healthcare expenditure is expected to reach c.a. 3% of GDP by 2025 **(figure 5.4.1)**.Per-capita healthcare expenditure is poised to increase at a fast pace. This is due to rising incomes, easier access to high-quality healthcare facilities and greater awareness of personal health and hygiene.

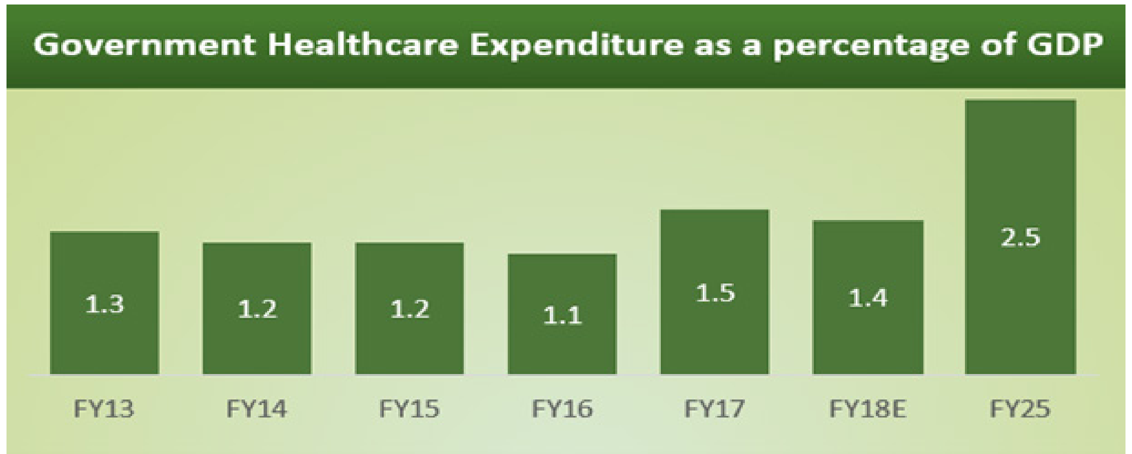

Figure 5.4.1: Predicted increase in government investment in healthcare industry.

The business opportunity of medical devices in India is attracting not only multinational companies, but also corporate houses with presence in related areas, such as pharmaceuticals, industrial ceramics and precision machining etc. The new entrants are exploring domestic acquisitions to gain a foothold in the market and also international acquisitions to gain product and technology advantage. In the national market, almost 80-85% of demand is met through imports. Imports are highest in-patient aids, implants, and instruments and appliances, while it is lowest in consumables **(figure 5.4.2)**. Consumables and Diagnostic Imaging sectors dominate the device market, occupying more than 50% of the market. There are around 750-800 device medical device manufacturers, with around 65% of them operating in the consumables segment.

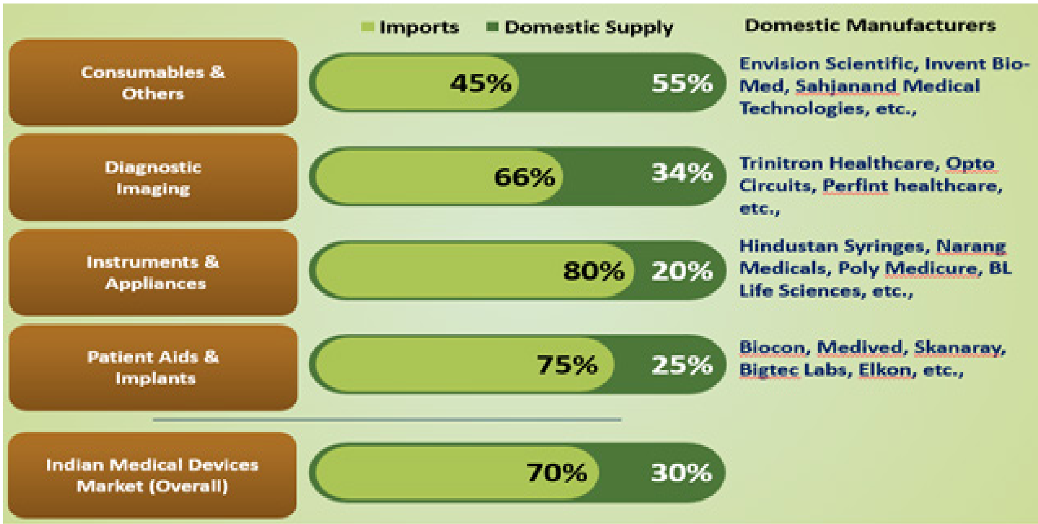

Figure 5.4.2: Indian Medical Device Industry Supply Landscape.

The Indian orthopaedic and prosthetic device market is valued at $660 million USD and the dental product market at $290 million USD in 2020. The overall projection is that the combined market will grow to $2.84 billion USD in 2024. Also, India serves as one of the important hotspots for medical tourism.

The global medical tourism industry was valued at $76 billion in 2018 and is expected to grow further at an average growth rate of 20%. India ranks highest among the other countries famous for medical tourism viz. Thailand, Malaysia, Singapore, India, South Korea, Brazil, Costa Rica, Mexico, Taiwan, and Turkey **(Figure 5.4.3)**. This provides another important reason to strengthen the Indian scenario of medical devices and biomaterials, as it will not only strengthen Indian medical system, but will also enable us to generate resources and monetary value by boosting the medical tourism industry.

Figure 5.4.3: Global status of medical tourism. India is the biggest stake holder in the global medical tourism industry.

5.5 India Value Chain v/s Global Value Chain

Several key factors for the escalating demand for implantable medical devices in India include improving healthcare infrastructure, rising geriatric population, which is more vulnerable to health disorders, increasing awareness about cosmetic surgeries, and approvals by the Government of India for a number of new implantable medical devices. Medical ceramics and composites market in India is expected to exhibit a double-digit growth during forecast period owing to wider acceptance of these materials in healthcare usage, like body implants, diagnostic imaging, surgical instruments, dental products, etc. The Indian implantable medical devices market size reached USD 94.8 billion in 2021, and the market is expected to reach USD 142.0 Billion by 2027, exhibiting a growth rate (CAGR) of 6.87% during 2022-2027. (Ref: https://www.imarcgroup.com/india-implantable-medical-devices-market). In another report by Frost & Sullivan Analysis, Industry Source; the CAGR from 2019 to 2024 is expected to rise by 10.5% **(figure 5.5.1)**. The global medical devices market is projected to grow from $495.46 billion in 2022 to $718.92 billion by 2029 at a CAGR of 5.5% in the period, 2022-2029.

The effect of global COVID 19 pandemic is unprecedented on the medical device industry across the world and a decline of -1.4% was observed in medical implant usage in 2020 as compared to 2019. In a report by Fortune business insight, with rise in the number of in-patient admissions, the demand for diagnostics and surgical equipment is rising exponentially. This is fuelling global implant manufacturing giants to invest considerable capital into R&D of new devices. For instance, Stryker, a global leader in orthopedic implants increased their R&D investment from USD 0.98 billion in 2020 to USD 1.2 billion in 2021. Medtronic reported an investment of USD 2.49 billion in 2021 as compared to USD 2.3 billion in 2020 **(see Figure 5.5.2)**.

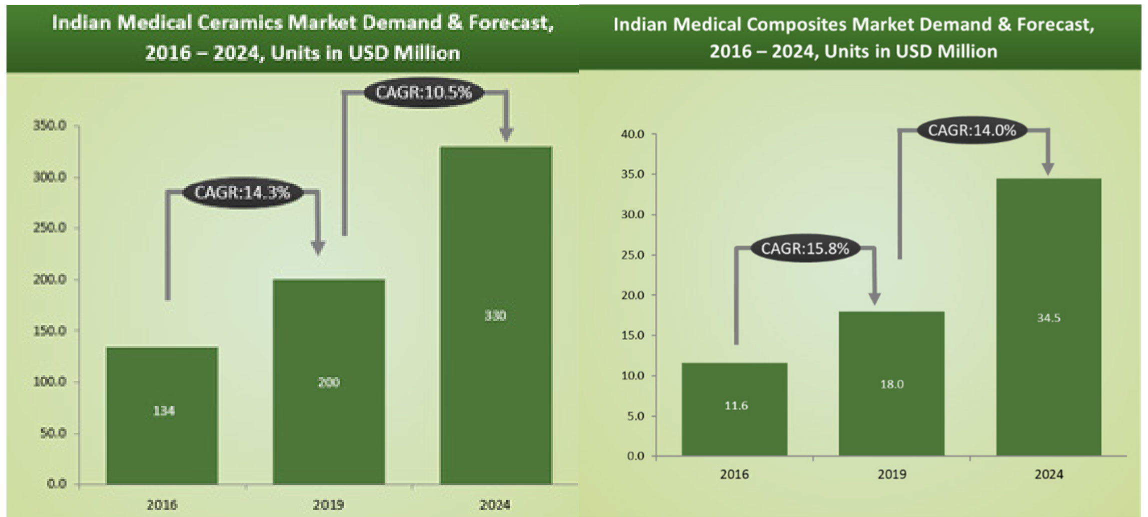

Figure 5.5.1: Indian market projection for medical devices, composites and ceramics demand.

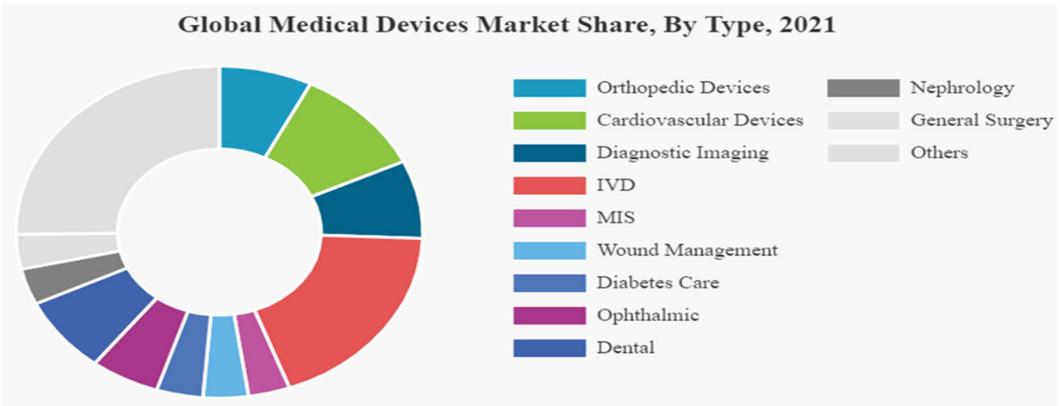

Figure 5.5.2: Global market share for different medical devices.
(Ref: https://www.fortunebusinessinsights.com/industry-reports/medical-devices-market-100085).

Against such a market prediction, the need for investment of technology, man-power, and capital towards indigenous development of biomaterials and implants is justified, and accelerated efforts in this direction are needed via a collaborative effort by academia, industries, regulatory authorities, and the government.

5.6 Gap Areas and Recommendations to Fill Gaps

- **Technology –**

1. **Lack of co-ordinated translational programs with mandatory industry involvement:**

   More robust technological advancement needs to be made by developing deep scientific understanding of the root cause of the problem and utilizing scientific tools to identify a feasible solution. The scientific community and industrial partners should collaborate for technologically driven output, rather than core science-based research.

2. **Lack of collaboration with clinicians during early stage of academic research:**

   Every PhD thesis in the field of biomaterials and implant design/manufacturing should have a clinical collaborator, who would define the unmet clinical needs. Once the academic research is over, clinicians can take over the results of academic study into translational research by collaboration with appropriate industries.

3. **Lack of technology translation:**

   Tissues engineered scaffold and scaffold loaded with stem cells have not been clinically translated. Indian biomaterial manufactures should maintain stem cell bank. Ready to use scaffold technology with sufficient backup should be made available for ease of utilization during surgeries. For example, scaffold should be made available in the operation theatre, where in stems cells can be loaded and implanted during an ongoing surgery. The regulatory clearance for such technologies needs to be established.

4. **Shortage of globally accepted certified testing centres:**

   Significant investment in testing and characterization of biomaterials/implants at NABL accredited facilities should be pursued to ensure globally competent technological value of indigenously developed biomaterial/implant.

5. **Lack of innovative indigenous design and development of implants:**

   Indigenously developed designs of implants should be empowered. Most of the designs in Indian implants used are adapted from western medical device manufacturers. Such approach lacks novelty and chances of legal issues are also high.

6. **Lack of skilled manpower:**

   The quality of technical education for semi-skilled or skilled manpower should be improved by implementing more practical training at grassroot level. Organizations like CSIR should participate in designing new curriculum and help organize seminars and practical workshops. technology students should be mandated to attend summer training in their core engineering industry to practically equip them with the upcoming developments of the industry.

7. **Innovation hubs:**

   It is suggested to create strategic innovation hubs with a comprehensive manufacturing, testing and computational facilities, which is essential for the accelerated development of biomedical devices from concepts to marketable products.

8. **Lack of understanding of regulatory compliance:**

a. CDSCO trial manufacturing license can be used for clinical study provided the final product for clinical study meets all the requirements and is similar to the final product for commercialization. The clinical study product should be sterilized, properly boxed and labelled with appropriate lot and batch numbers and all other necessary details.

b. Proper biocompatibility testing should be selected for the material based on the end application, based on biocompatibility matrix given in ISO 10993 standards

c. All the ASTM and ISO standards should be properly mentioned with appropriate notations, part and year of amendments.

d. All the products should comply with the regulations as laid by MDR (2017), which was enforced from Jan 1, 2018 and the related amendments are to be followed.

e. Clinical studies may not be required when basic design is same with predicate device.

5.7 Government Support

- **Government regulations:**
  It is recommended to formulate an accelerated pathway for regulatory approval involving experts that can be approached to discuss the regulatory requirements at any point in the research and development process, in particular for clinical trials. It is recommended that agencies should be formed to help facilitate and organise clinical trials, in line with regulatory requirements. Also, it is recommended to simplify procedures to seek patient consent prior to clinical trials and ethical approvals for animal studies.

- Higher funding from government agencies for technologically driven research (TRL 6-7).

- Government regulations for the development of indigenous implants should be eased to support the indigenous technology over imported technology, without compromising the quality of the final product.

- **Less participation by higher education institutions:**
  Allocating higher and advanced national labs and institutions to mentor the Tier 2 and Tier 3 institutions to develop a vibrant and inclusive ecosystem.

- Import and export guidelines should be regulated. The services should be for the indigenous population first and then the surplus should be exported.

- Policy level changes to mandate single use devices for the development of new business and industries.

- Subsidy and policy changes by government to ensure manufacturing requirements and targets are met by the industries.
  Indian government can specify and limit the cost for every implant and medical devices used in the country. Under such restrictions, it becomes difficult for the manufacturers in certain cases, to meet the stringent government rules, while maintain the global product quality. Hence, government should provide subsidies and import relaxations to ensure such cost related marginalization and limits are met.

5.8 Collaboration

- **Lack of industry-institution collaboration:**
  Small and long-term collaboration is needed among academic institutions, industrial partners, and commercialization partners, regulatory consultants and QMS personnel in establishing a translational research ecosystem. **(Figure 5.8.1)**

- Goals of each organization in the collaboration need to be clearly defined as per the available expertise and facilities.

- Every biomaterial product should have regulatory profiling to be done by regulatory consultant with related domain knowledge.

- Regulatory consultant and QMS personnel should be involved from the conceptualization stage of a translational project through technology transfer to first commercial batch.

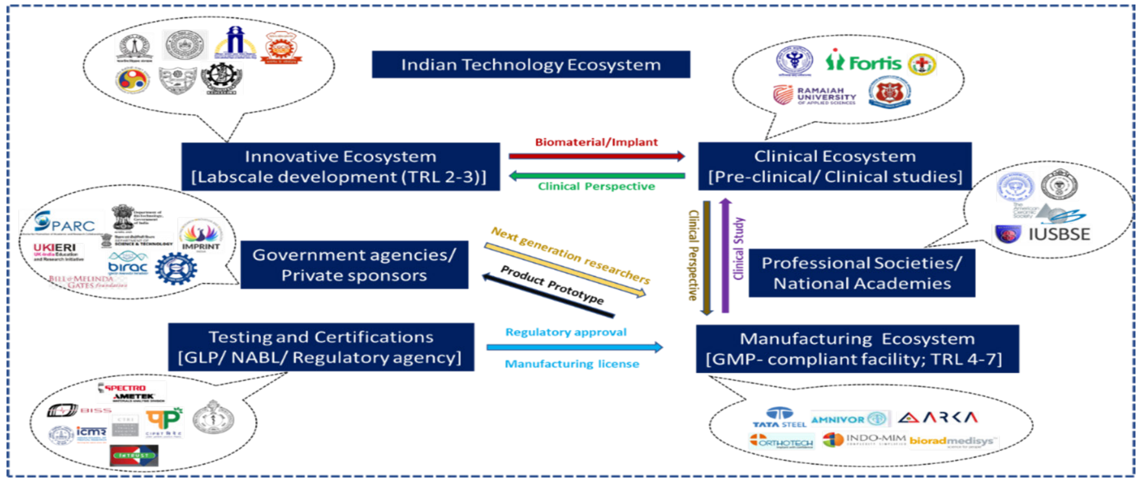

Figure 5.8.1: Interdisciplinary and Translational Ecosystem in India

5.9 Role of the Stakeholders such as, Government, Academia, Industry and Research Institutes

- **Recommendation (Small, Medifum, and long term) and conclusion**

One of the important lacunae in the entire ecosystem is the lack of strong presence of indigenous industry to complete the cycle of 'science-to-product' innovation. To this end, the major recommendations are outlined in **Figure 5.9.1** and more details are given below.

- **First Three Years (3)**

1. Establish strategic policy centres to conduct market research on biomaterials and implants. The dynamic changes in implant market should be carefully studied and the market research results should be accessible to industries, MSMEs and start-ups.

2. Lack of raw material manufacturers is one of the biggest bottlenecks faced by the Indian industries and academic organizations for advanced research and production. Government policies should be made for establishing new industries for raw material and resin manufacturing *viz*. polymers, ceramics, metal and alloys. In an article published in International Journal of Information Research and Review, Indian imports 70% of raw materials for pharmaceuticals and implant manufacturing from China (*Gupta et. al. Vol. 08, Issue, 03, pp.7208-7219, March, 2021*)

3. Strengthen and expand KIHT/AMTZ–like ecosystems across different strategic locations in India to create strategic innovation centers to facilitate transfer of clinically validated technologies from academia/national labs to established industry. Such centers should develop the capability for commercial scale production of biomedical grade materials such as hydroxyapatite powders/blocks/granules, Ti6Al4V/ stainless steel/ CoCrMo blanks, UHMWPE blocks, bioglass blocks and biodegradable polymers (PLA, PLGA, etc.).

4. KIHT/AMTZ group of institutions should maintain a national registry of medtech innovations from across the country. This should be made available to companies, which can then analyze the commercialization potential of the innovations and take the promising ones to market.

5. The healthcare sector should have significant investment from the Government for the manufacturing of biomedical materials/implants, and for an appropriate regulatory framework for the sector; thereby should minimise the import of sub-standard or even re-called devices. Competitive cost-structure analysis of newly indigenous implants and materials with respect to similar products currently sold worldwide, is warranted.

6. Promote Industry-focused clinical excellence as a driver of translational research and involve industry, right from TRL-1 stage, while conceiving translational research programs at strategic innovation centers. This demands commensurate funding mechanisms that strongly emphasize collaborative research with at least one mandatory industry partner with tangible incentives, to ensure impact beyond publications.

7. Mandatory management training for biomedical entrepreneurs, so that they learn about strategy, branding, product positioning, assessing risk factors, development of business and commercialisation plans and marketing, sales and distribution strategies of biomedical implants and devices.

8. Industry experts to participate as adjunct faculty in professional education (e.g. PhD program in Biomedical Engineering) to help build a knowledge base on market opportunities and needs, and also commercialisation of products and technologies.

9. Create incentives to attract indigenous entrepreneurs, recognise incubators as for-profit companies and enhance the number of start-ups (both private and public institutional). Engage with the next generation of researchers to develop an entrepreneurial spirit and awareness, which is very important for developing the next generation of start-up founders.

10. An IP training certification of all innovators before receiving funding, to expose them to IP-related litigation procedures and also protocols with freedom to operate analysis. Valuation of IP as an intangible asset for start-up valuation.

11. National translational research institute similar to SCTIMST,Thiruvananthapuram should be established with more emphasis towards orthopedic biomaterials and implants., as market share of orthopedic, musculoskeletal and dental implants are comparatively higher than other medical implants. The translational institute should have an eco-system comprising of biomaterial scientists, key opinion leaders, Indian industrial partners and advances research institutes.

- **First Five Years (5)**

1. Establish and strengthen the innovation ecosystem in start-ups/MSMEs/industry. Promote more standard contract agreements between industry and academia to accelerate engagement with single or multiple universities. It is recommended to introduce an optional tenure of biomedical researchers in industry for 6 months every 2-3 years in their career. Researchers from academia/national labs should be allowed to act as part-time consultants for industry R&D programs. Without innovation, they may not be able to generate patents, and as a result they might fail to compete with international big players. Incubators must have specific skills to assess the commercial potential of technologies and incubatees should be mentored by a pool of mentors for innovation and translation.

2. Enable Indian MSMEs to form viable contract manufacturers with market penetrating strategies by selling products to established companies, such as Meril Healthcare, Stryker, Smith and Nephew and Zimmer. For example, the top global orthopedic manufacturer companies are consuming 1.5 to 2 million femoral heads (an orthopedic implant component used in total hip joint replacement surgeries) a year. Also, the dental market in India presents a good opportunity, since there are not even a handful of local manufacturers yet.

3. Improve the country's knowledge of the manufacturing process and its effects, through courses on automation, information from sensors, data exchange (Fourth Industrial Revolution of digitisation, i.e. Industry 4.0) and on minimising environmental impact.

4. Establish Research parks at selected NITs and institutes of eminence to foster incubation of start-ups; build large research hubs with state-of-the-art facilities in the area of advanced manufacturing (e.g. biomedical prototyping etc.)

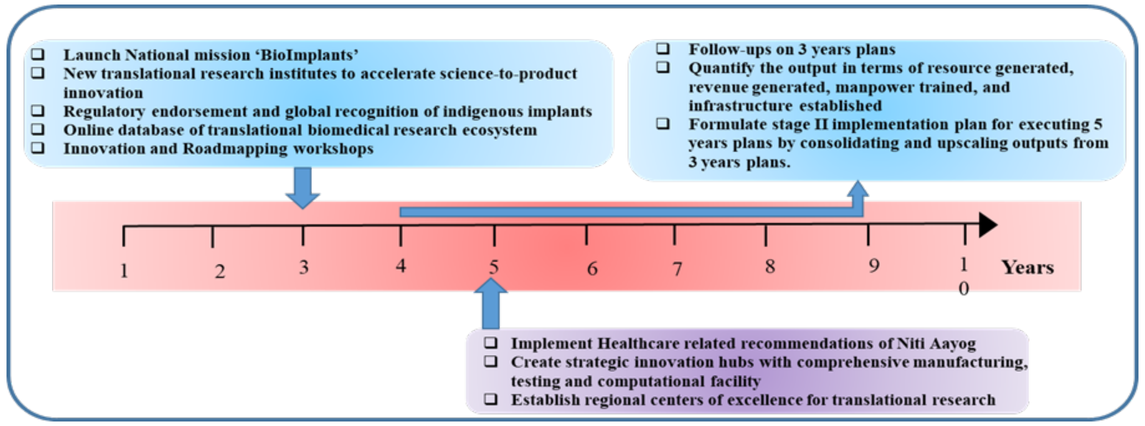

Figure 5.9.1: Short- and long-term plan suggested for advanced materials for biomaterials and implants

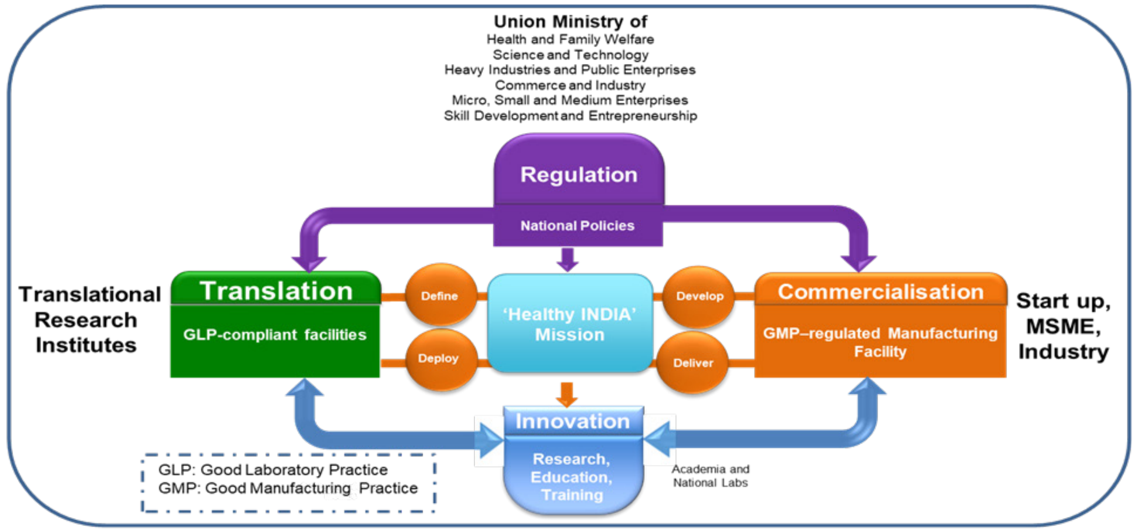

Figure 5.9.2 Translational ecosystem for biomaterials and implant development for healthy India

Milestone	Tentative Timeline								
	0-6		12-18	18-24	24-30	30-36	36-42	42-48	48-60
Establishing and formulation of task force for advance materials for biomaterials and implants									
Laying out strategies to encounter the raw material needs and policy level changes for Indian industries									
Formulation and launch of national mission on 'BioImplants'									
Evaluation of milestones under advanced materials by quantifying the resources produced									
Formulation of consortium of industries and academic partners for Indian implant requirements									
Recommendations for policy level changes to NITI Aayog for improving indigenous development of raw materials an implant									
Creating strategic innovation hub with manufacturing and testing facility available to all the Indian partners									
Creating of a data bank for all the resource and information generated									
Establishing regional centres of excellence									
Evaluation of milestones and laying out future action plans									

5.10 Chapter Contributors

On behalf of the CII National Mission for Technology, Innovation and Research, we would like to acknowledge and express gratitude to the following for their contributions in the Chapter on Biomaterials & Implant:

- Prof. Bikramjit Basu, Professor, Indian Institute of Science, Bangalore
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- Sushant Banerji, Founder & CEO, Orthotech

CHAPTER 6:

COMPOSITES

6.1 Composites Materials and their Background

A composite material is one comprised of two or more constituent each of which has distinct physical or chemical properties, that, when combined, generate a material with characteristics distinct from the constituent materials' separate features. Figure 1 is a diagram representing broad classification of composite materials.

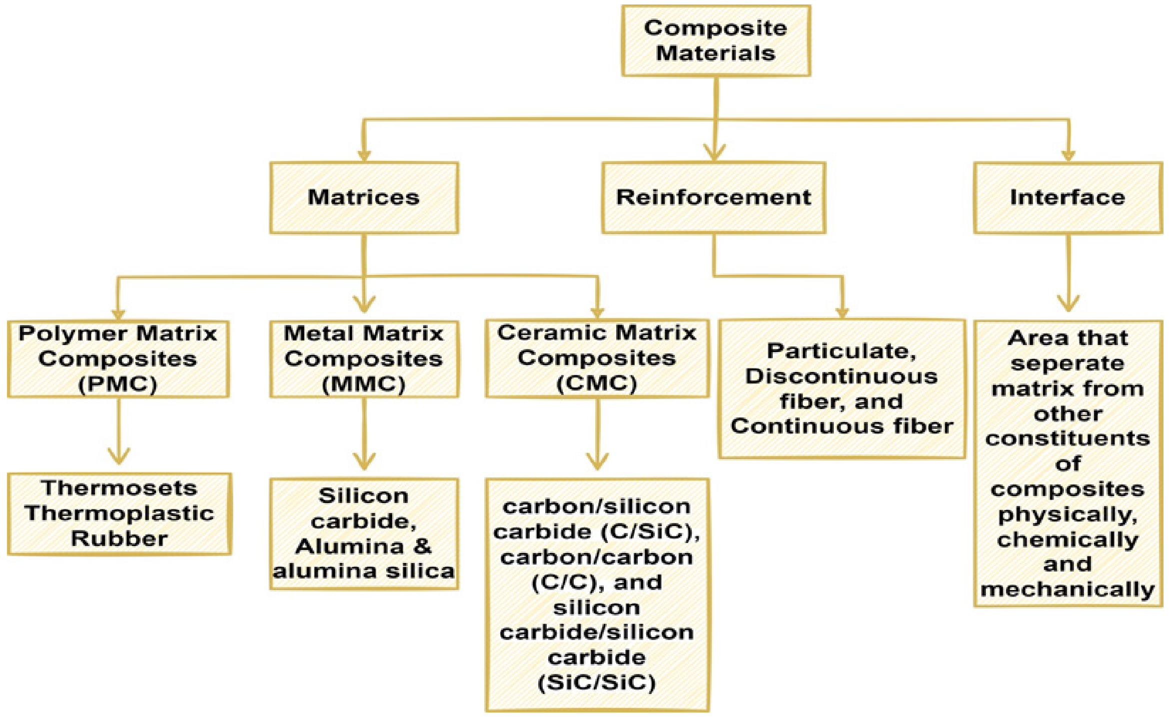

Figure 6.1.1. Classification of composite materials.

From ancient times, builders, artisans, engineers, and manufacturers continued to develop composites of a more comprehensive array of materials for sophisticated applications. Composites: the ever-emerging member of the materials family since BC, with its kinds and a wide variety of applications.

a. **3500 BC-** Mesopotamia: The first known use to manufacture plywood with glued wood strips at different angles
b. **Before BC 2100-** Egypt: Death masks through layers of linen or papyrus soaked in plaster and during
c. **BC 1500-** Egypt: Use of straw to reinforce mud bricks, pottery and boats.
d. **During Christ's era**: Concrete of lime and mortars and materials superior to cement.

e. **During 1000- 1200 AD**: the first composite of wood, bamboo, and silk bonded with natural pine resin.
f. The Mongols created the first composite bows in **1200 AD** using a combination of wood, bamboo, bone, cattle tendons, horns, silk, and resin from natural pine trees. The most feared weapons on earth up to the invention of firearms in the 14th century were these small, strong, and incredibly accurate bows.
g. The **1930s** are regarded as the most significant decade for the development of resins still in use today in the composites industry.
h. Some of the key present generation composites are also discussed along with pros and cons [1–3].

6.2 Metal Matrix Composites (MMC)

A family of materials called metal matrix composites (MMCs) consists of a metal fused with another component. Both physically and chemically different phases of these two components are present. The other ingredient appears as fibers or particles to serve as a reinforcing material, with the foundation material being a metal matrix. The aim of creating such a material, as with other metal matrix composites, is to improve the qualities of the metal matrix by adding supplementary features that the reinforcement gives. Some of the advantages of MMCs are high heat resistance, fire resistance, inability to absorb moisture, radiation resistance, and increased resistance to wear and tear. But it lacks in terms of higher cost of some material systems, relatively immature technology, complex fabrication methods for fiber-reinforced systems (except for casting) and limited-service experience.

6.3 Ceramic Matrix Composites (CMC)

The form of composite known as ceramic matrix composites uses ceramics as both the matrix and the reinforcement. The matrix material keeps everything together while the reinforcement offers its own qualities. These composites were created for applications requiring high levels of thermal and mechanical performance, as those in the chemical, nuclear, aerospace, and ground transportation industries. Ceramic fibres or whiskers inserted in a ceramic matrix are the main component of ceramic matrix composites (CMC). These inorganic materials, which are typically non-metallic and frequently employed at high temperatures, fall within the broad category of ceramics.

- **Two categories can be used to categorize ceramics:**

1. Ceramics that are traditional or conventional are typically monolithic in shape. They contain pottery, tiles, bricks, and a variety of other art supplies.
2. Advanced or high-performance ceramics, the creation of which frequently involves chemical processing. These include titanium, silicon, zirconium, and aluminum nitrides, oxides, and carbides.
3. Some of the advantages of CMCs are high thermal shock and creep resistance, high temperature resistance, excellent resistance to corrosion and wear, inertness to aggressive chemicals. But it lacks when it comes to impact resistance, brittle fracture, part size and shape limitations, defect size effect, limited load level during sliding.

6.4 Polymer Matrix Composites (PMC)

Fiber-reinforced polymer (FRP) composites are comprised of a reinforcing fiber in a polymer matrix. Most commonly, the reinforcing fiber is fiberglass, although high-strength fibers such as aramid, carbon and basalt fibers are used in advanced applications. The right combination of polymer and reinforcement can produce some of the most robust materials for their weight that technology has ever developed [4,5]. FRP composites are incredibly versatile—it is possible to produce an endless variety of composites to meet the desired properties for specific applications. Designers and engineers can modify FRP's physical and chemical characteristics by selecting a suitable combination of materials. For example, while glass fiber-rich reinforced structures generate maximum physical strengths, high resin content structures render maximum chemical resistance. An engineer can specify the combination of the two or more materials to create an optimum design. Additionally, FRP composites may contain fillers, additives, and core materials to enhance the properties of the final product. FRP composites can also be engineered for additional attributes, such as light transmission, translucence, fluorescence, and conductivity [6–8].
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6.5 The Timeline of the Evolution of FRP Composite it as follows:

a. The first glass fiber was introduced in **1935** by Owens Corning (USA), which also gave rise to the fiber-reinforced polymer (FRP) market.
b. Unsaturated polyester resins were first patented in **1936.** Unsaturated polyester resins are still the material of choice for making composites because of their ability to cure. Other more performing resin systems, such as epoxies,

became accessible around **1938.**

c. Composite materials started to appear more frequently in popular manufacturing and construction by the middle of the 1990s. Thermoset composites were widely used as substitutes for conventional materials like metal and engineered thermoplastics in the appliance, construction, electrical, and transportation sectors. The usage of composites in daily life increased in both the consumer and industrial markets.
d. The development of the 787 Dreamliner (Boeing) in the middle of the 2000s validated composites for highly rigid and high-strength applications, and the continued advancement of finish technology, such as PVD and THERMTIALTM, increased the number of applications in the consumer goods, appliances, and automotive sectors.
e. Research on composites is nowadays supported by funding from governments, businesses, and academic institutions. Accelerated innovation is made possible by these investments. Specialized businesses like aerospace composite businesses will have a position in the sector. Composite materials for use in airplanes and composite sheets for marine applications are two areas that continue to see inventive progress.

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6.6 Potential and Penetration of FRP Composites at Global Platform

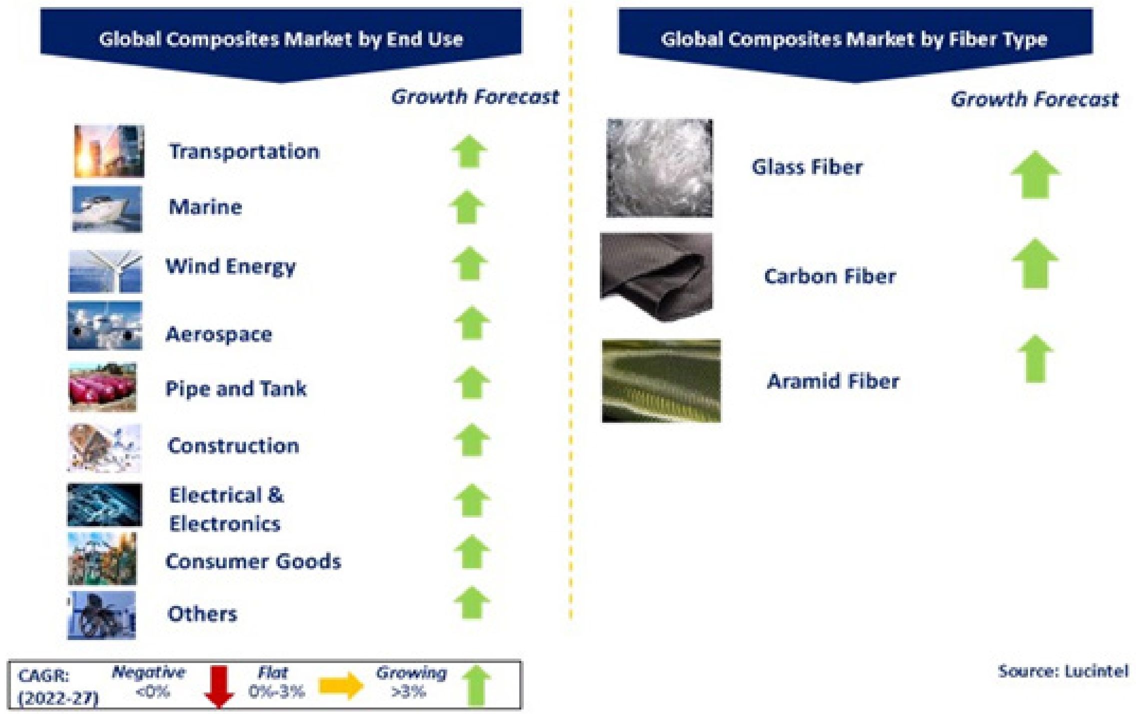

Figure 6.6.1. The speculated growth of key market segments [10]

The desire for more robust, lighter, and more ecologically friendly goods is met by other materials, including bio-based polymers and environmentally friendly resins made from recycled plastics. The newly created fibers and resins will expand both in general and specialized uses [4,9]. This can be better understood by the trends shown in Figure 6.6.1 and Figure 6.6.2.

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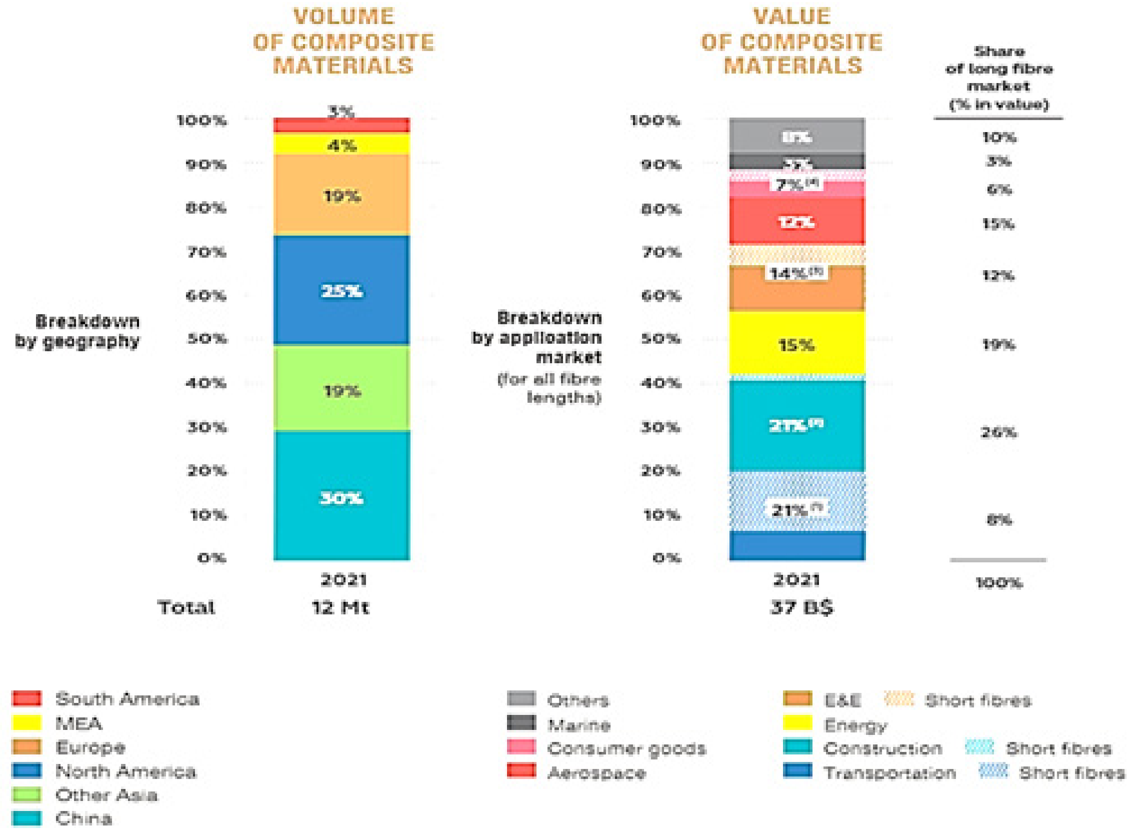

Figure 6.6.2. Global composite market in 2021 [11]

6.7 FRP Composites Constituents

Polymers are long-chain molecules containing one or more repeating units of atoms joined together by strong covalent bonds. A polymeric material is a collection of a large number of polymer molecules of similar chemical structure but not necessarily of equal length. The classification of polymers can be clearly seen in Figure 6.7.1.

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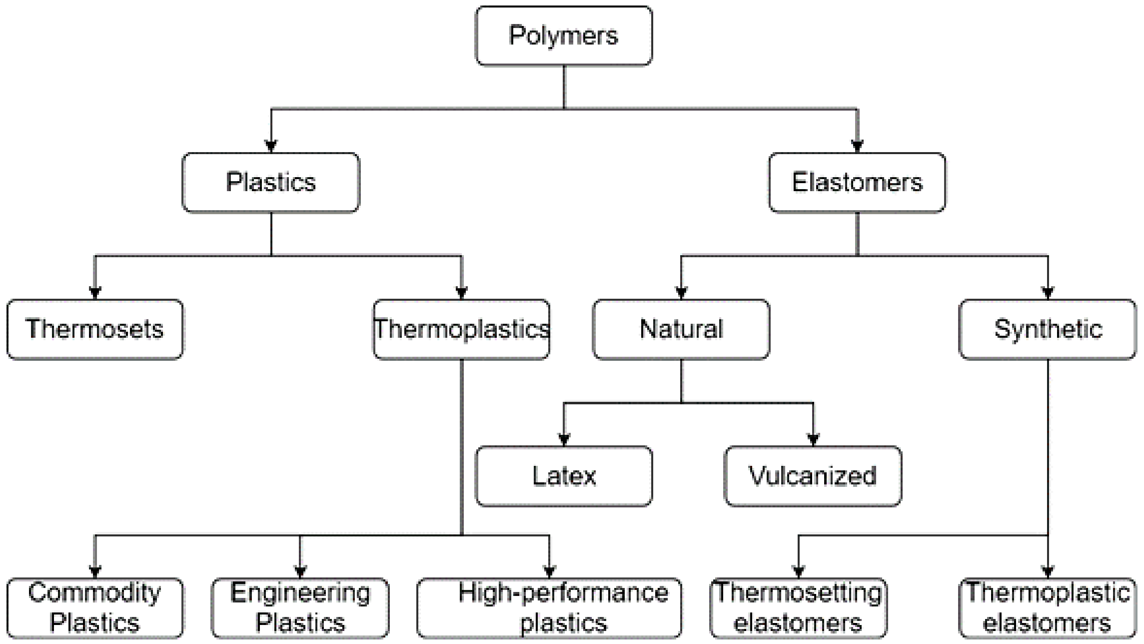

Figure 6.7.1. Classification of engineering polymers [12]

Thermosets are more resistant to most of the solvents and fluids encountered in service, whereas many thermoplastics are very susceptible to solvents. Semi-crystalline thermoplastics are pretty resistant to solvents and other fluids. Some of the critical differences between the thermoset and thermoplastic polymers are listed in Table 1 and the FRP fabrication techniques are mentioned in Table 2.

Table 1. Comparison of Thermoset Polymers and Thermoplastic [13]

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Thermoset	**Thermoplastic**
Easy to process due to low viscosity liquid resin	Difficult to process as viscosity is even high above the melting point.
Temperature and pressure requirements are less for processing.	Relatively high temperature and pressure requirements are less for processing.
Limited storage life.	Unlimited storage life.
Higher strength and modulus	Tougher and less brittle.
Post curing often necessary for optimum properties.	Post moulding treatment is recommended.
Low tensile elongation	Relatively high tensile elongation
Undergo less creep	Undergo more creep

Table 2. Fabrication techniques of FRP composites and its uses [11].

Technology	**Description**	**Used for**
Autoclave	Piled up prepreg sheets are placed in a heated pressure vessel to cure the pile with heat and pressure	Structural, exterior and interior components like nacelle, side panels, doors etc.
Compression molding	A material preforms (SMC, BMC etc.) is placed in the female mold and the male mold is closed on top of it for curing under heat and pressure	Structural, exterior, interior components like engine hood, fenders, under-hood components, engine shield, arm rests
Resin transfer molding (RTM)	A dry fiber mat is placed in a closed mold which is then infused with low viscosity resin injected through an inlet from outside	Structural parts like empennage, flaps, spoilers
Vacuum infusion molding (VIM) / Vacuum assisted RTM (VARTM)	A modified version of RTM where a vacuum bag is laid on a dry fiber mat and a low viscous resin is released inside to infuse the dry fibers under vacuum to minimize void content and achieve greater strength.	Large components like body panels and roof
Injection Molding (IM)	Resin mixed with chopped fibers is heated and injected into a closed mold which is then cooled and cured	Complex components including engine blades, bulkhead, circuit breaker tags
Structural Reaction Injection Molding (SRIM)	A modified version of IM, dry fibers are placed inside the closed mold before the resin is injected to ensure an even distribution of fibers in the composite	Structural components with low cosmetic value like chassis, battery box
Pressure press	An improvement on autoclave process of curing prepregs by directly heating the mold surface instead of mass-heating the mold to reduce curing time by ~75%	Exterior parts like bumpers, fenders, side skirts, spoilers

Autoclave	Piled up prepreg sheets are placed in a heated pressure vessel to cure the pile with heat and pressure	Piled up prepreg sheets are placed in a heated pressure vessel to cure the pile with heat and pressure
Thermoforming	A filled thermoplastic laminate is heated to make it viscous and a mold is pushed onto the viscous laminate from below to bring it to shape	Interior and exterior components using thermoplastics like instrument panel, seats, body panels, engine hood
Extrusion	Filled, viscous resin is pushed from a funnel through a heated tube against a mold to get a continuously cured profile	Engineering thermoplastic laminates used as intermediates and some components with uniform cross-section like side sills and crash structures
Pultrusion	Wet fibers are pulled through a mold that leads to more consistent and accurate fiber spread to achieve more predictable and consistent strength in the composite part	Spar caps

Fiber epoxy composites have been used in aircraft engines to enhance the system's performance. The pilot's cabin door of aircraft has also been made with fiberglass resin composites, which are now used in other transport systems. Based on end-use industries, such as wind energy, transportation, pipes and tanks, marine, building and infrastructure, electrical and electronics, aerospace and military, the GFRP composites market is divided into several segments. In terms of both volume and value, the transportation end-use sector dominated the global GFRP composites market in 2016. The weight and improved fuel economy of GFRP composites are the main reasons for the significant demand in the transportation sector.

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Table 3. Comparison of conventional metals and FRP composite's properties [14].

Materials	**Density g/cm3**	**Modulus GPa**	**Tensile strength MPa**	**Yield strength MPa**	**Specific modulus, 106 m**	**Specific strength, 103 m**
SAE 1010 steel(cold-worked)	7.87	207	365	303	2.68	4.72
AISI 4340 steel (quenched and tempered)	7.87	207	1722	1515	2.68	22.3
6061-T6 aluminium alloy	2.70	68.9	310	275	2.60	11.7
7178-T6 aluminium alloy	2.70	68.9	606	537	2.60	22.9
Ti-6Al-4 V titanium alloy(aged)	4.43	110	1171	1068	2.53	26.9
17–7 PH stainlesssteel (aged)	7.87	196	1619	1515	2.54	21.0
INCO 718 nickel alloy (aged)	8.2	207	1399	1247	2.57	17.4
High-strength carbon fiber–epoxy matrix (unidirectional)	1.55	137.8	1550	–	9.06	101.9
High-modulus carbon fiber–epoxy matrix (unidirectional)	1.63	215	1240	–	13.44	77.5
E-glass fiber–epoxy matrix(unidirectional)	1.85	39.3	965	–	2.16	53.2
Kevlar49 fiber–epoxy matrix(unidirectional)	1.38	75.8	1378	–	5.60	101.8
Boron fiber–6061 Al alloy matrix (annealed)	2.35	220	1109	–	9.54	48.1

6.8 Major Applications of FRP Composites

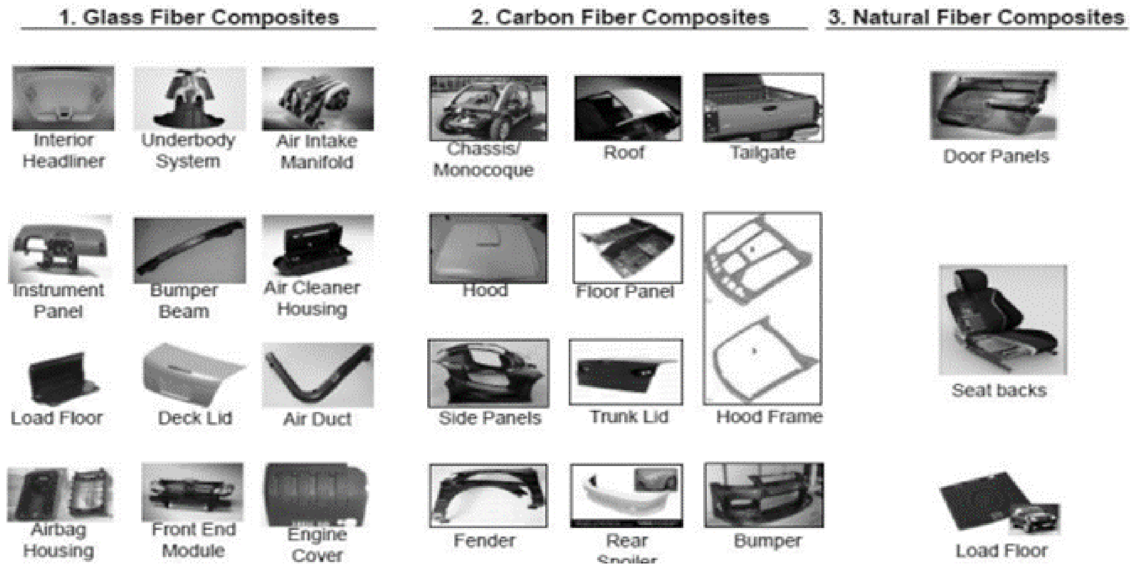

Figure 6.8.1. Entry applications of glass fiber, carbon fiber and natural fiber composites in automotive sector [15]

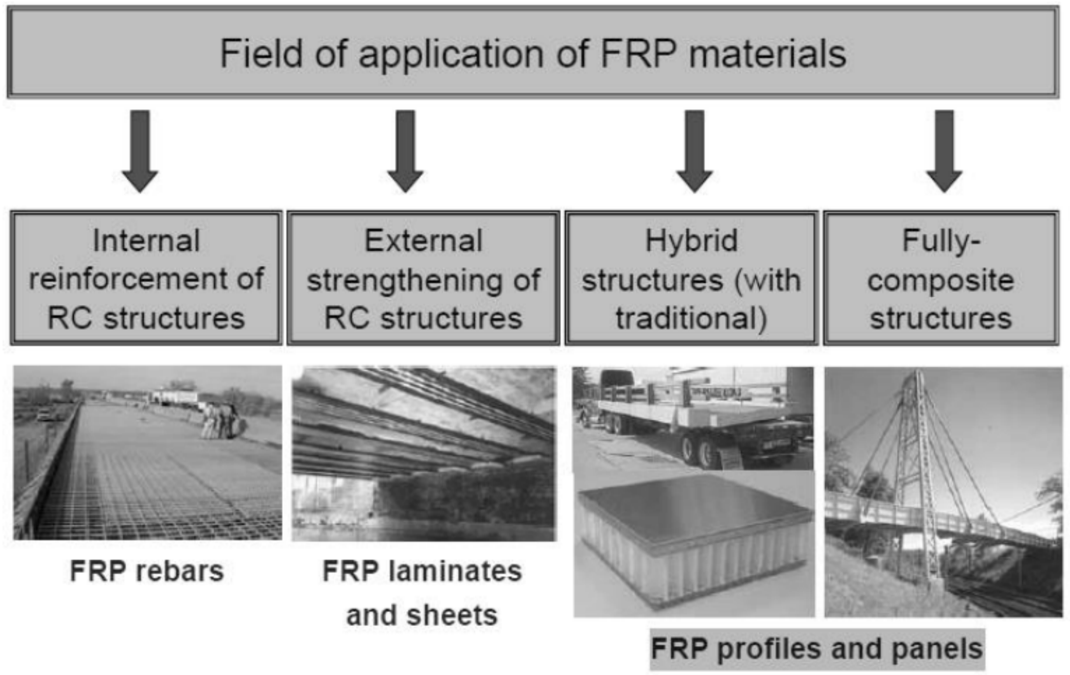

Figure 2.8.2. The significant fields of FRP composites applications [15]

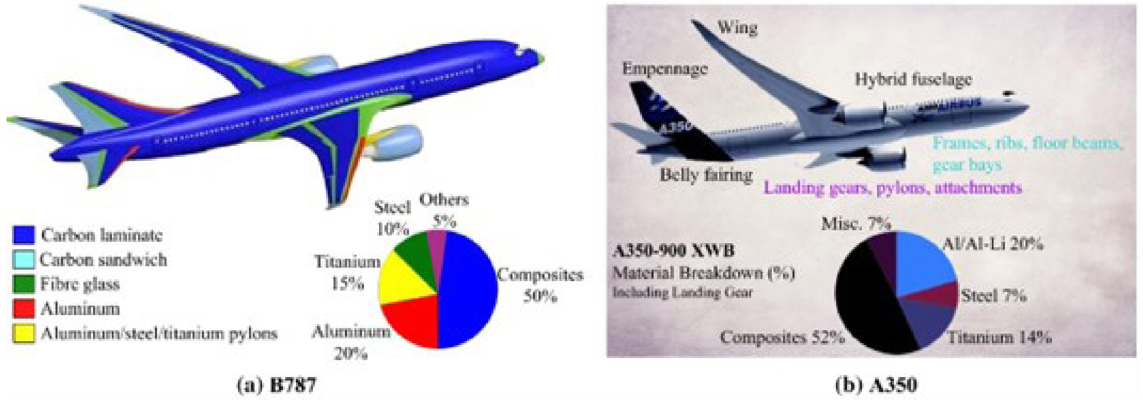

Figure 6.8.3 Distribution map of composites in (a) B787 and 797 (b) A350-900 XWB [16]

6.9 The Strategic Importance of FRP Composites for India

India is on the cusp of exponential structural expansion in the areas of mega civil structures, automobiles, renewable energy, railways, marine vessels and structures, aerospace structures and satellites. The traditional materials that India is primarily dependent on presently for its new-age structures, such as steel and aluminum possess immense strength and reliability in terms of the amount of research and development that Indian engineers and researchers have already put into them. These materials also happily enjoy a systematic and foolproof supply chain that has been built over many decades. However, these materials are plagued with significant drawbacks. Corrosion and the subsequent loss of materials is an area of prime concern. India is estimated to lose approximately 5-7 % of its gross domestic product (GDP) every year through corrosion. In this regard, FRP composite materials are highly advantageous as they have superior corrosion resistance. The polymeric matrix in which the valuable reinforcing glass and carbon fibers are embedded shield the reinforcements from degradation attacks and make these materials extremely durable.

Furthermore, traditional metallic materials have high densities, increasing transportation and assembly costs. Additionally, more energy and labor are needed for the construction of these materials. A major benefit of FRP composite materials is that they are incredibly light in weight. The densities of FRP composites have been compared with the traditional materials in Table 3. The basic idea of developing composite materials is to benefit from the desirable properties of the constituent materials. FRP composite materials possess a high degree of tailorability, i.e., to develop customized materials with very specific properties as per application requirements.

Tailorability plays a major role in enabling innovative and new-age designs and drastically reduces materials wastage. The chief reason that FRP composite materials are aimed to be the present and the future of advanced structural materials is that they possess not only all of the aforementioned desirable properties but also commendable mechanical properties. The mechanical performance of FRP composites has been recorded to be at par with or surpassing that of traditional materials. The various mechanical properties of FRP composites can be compared with other materials in Table 3.

6.10 The Global Value Chain of FRP Composites

- The composite industry at the global scale is in recovery after a decline in 2020. The overall industry is back to a level comparable to 2019 (average growth rate of 2% p.a.).
- In volume, the composite materials market is estimated at ~ 12.1 Mt, and Asia is the first market in value (50%), followed by the Americas (~ 25-30%) and EMEA (~25%).
- In value, the market for composite materials is estimated to be above 37 B$ in 2022. The main application sectors are transportation and construction (20% each), energy/ E&E / aerospace (10-15% each), consumer goods/marine (< 10% each). The American and EMEA markets still have a higher added value than the Asian market.

6.11 Key producers and their Volumes and Financials

Table 4. Country-wise list of key producers [17]

Producer	Product Type	Financials
China		
Jushi Group	Fiberglass Mats and Woven Rovings; Fiberglass Products for Thermoplastics; High-Performance Hybrid Fiber	8.51 Billion USD
Taishan Fiberglass	Fiberglass pipes, tanks, wind energy solutions, mats and fabrics	
CPIC	Direct Roving; Multi-end Roving; Chopped Strand	
USA		
Owens Corning	Roofing; Insulation; Commercial & Institutional Insulation; Industrial & Mechanical Insulation	7.87 billion USD
PPG Industries	Coatings, Removers & Cleaners Packaging; Custom Solutions&Chemical Packaging Services; Sealants Aircraft Fuel Tank, Fuselage, Windshield, Conductive And Specialty	29.84 billion USD
AGY Holding	E-Glass, Glass products For Electronics specialty Fibers	
Japan		
Nippon Sheet Glass	Glass And Glazing Products For Architectural, Automotive And Established Creative Technology	360 Million USD
Asahi Fiber Glass	Thermal Insulations, Acoustic Absorbing Materials and Roofing Materials for Housing, Buildings, Facilities and industries	
France		
Saint Gobain (France)-ADFORS	Textile and coating technologies use fiberglass yarns, synthetic, and natural fibers.	

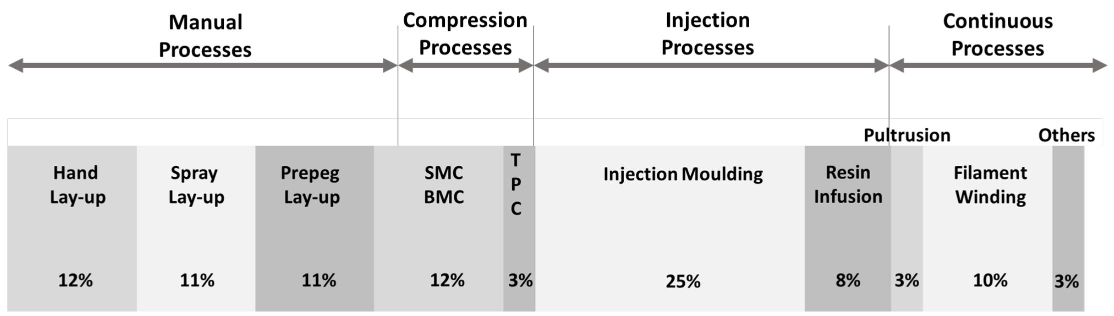

Figure 6.11.1 Distribution of FRP composites processing techniques

6.12 Key Market Segments – Current and the Evolving Market Segments

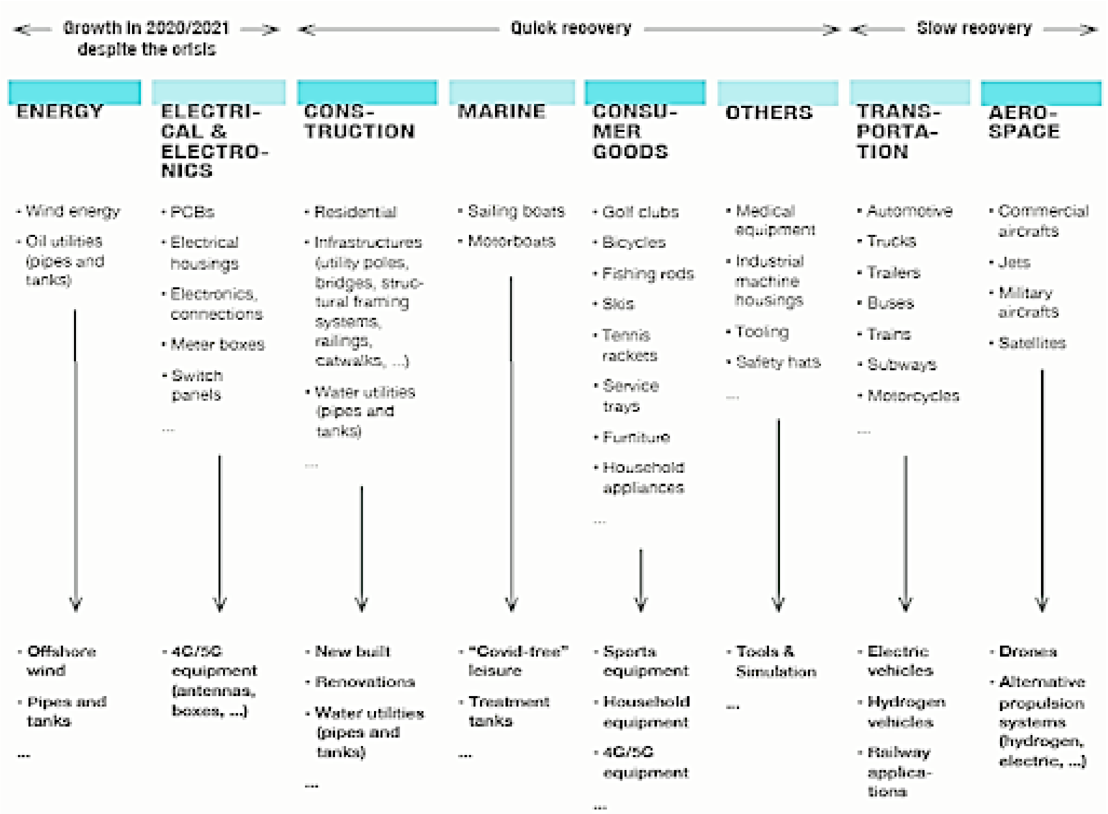

Figure 6.12.1 Summary of expected key future trends for composites by application sector [11]

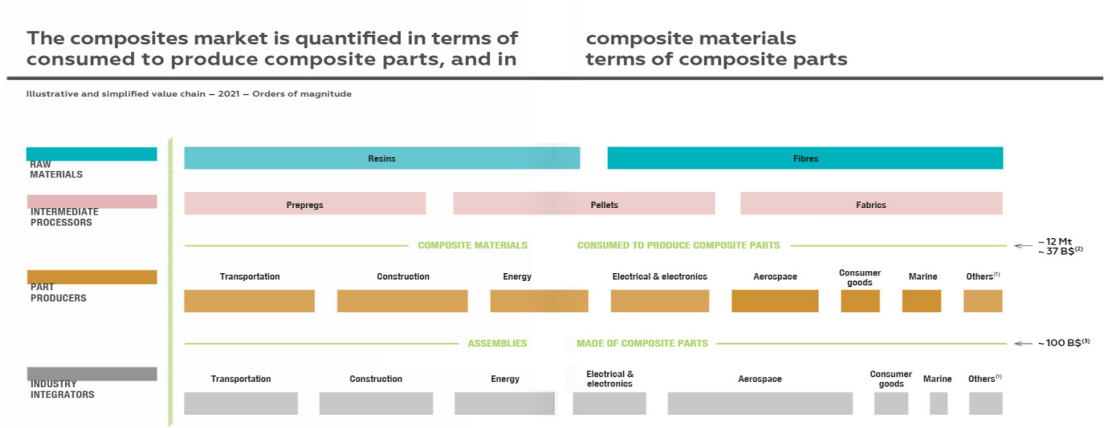

Figure 6.12.2 Illustrative and simplified value chain (2021)-orders of magnitude [11]

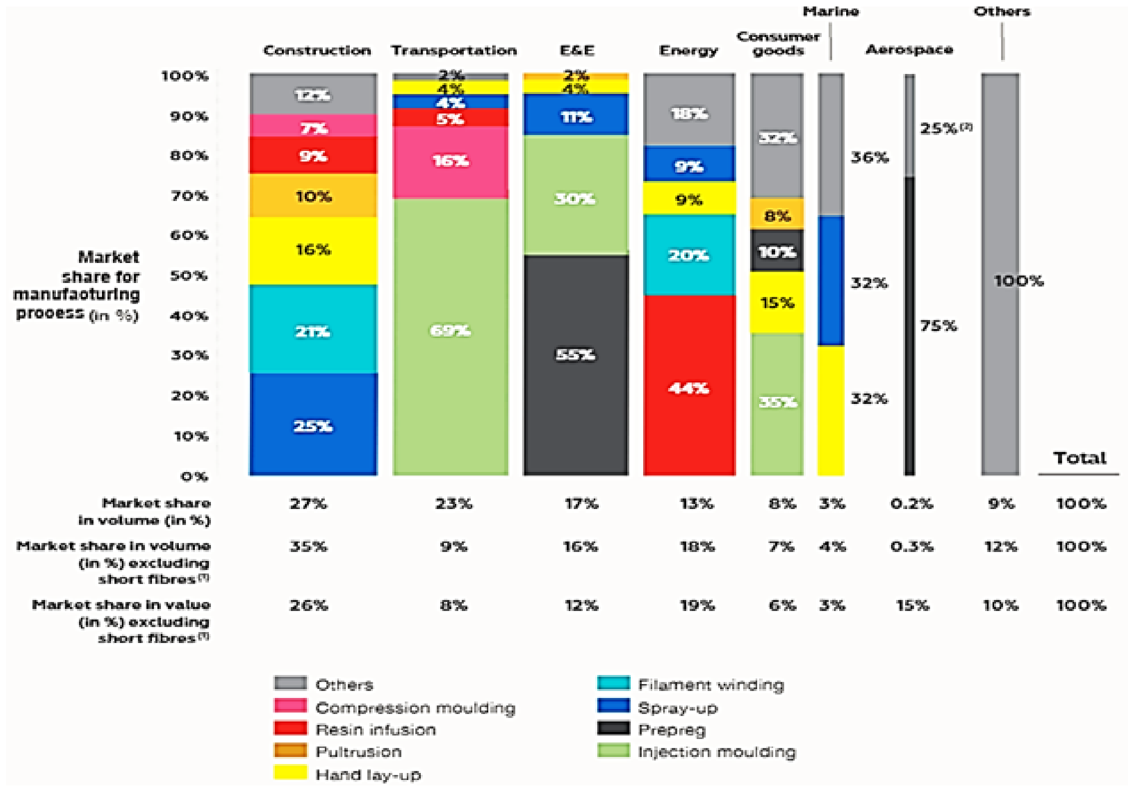

Figure 6.12.3 Prevalence of processes used by application sector throughout world (2020) [11]

6.13 Market Size – Both Current and Projected for 2030

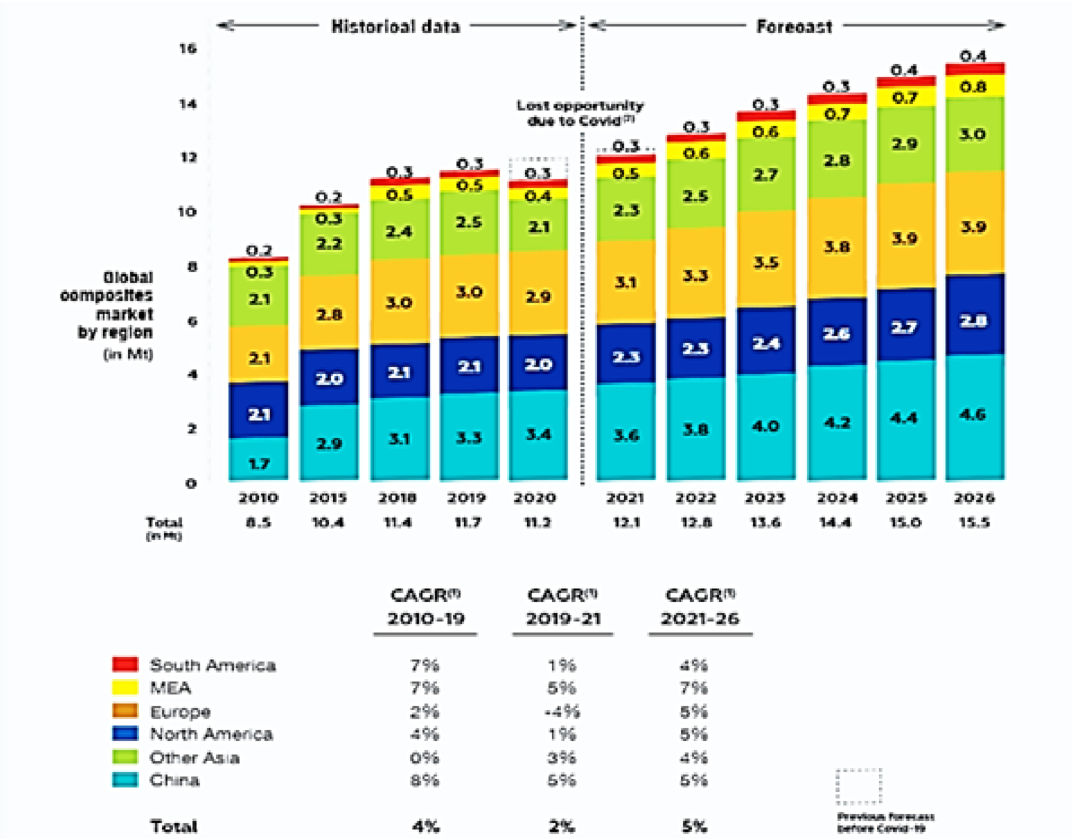

Figure 6.13.1 Market forecast for composites [11]

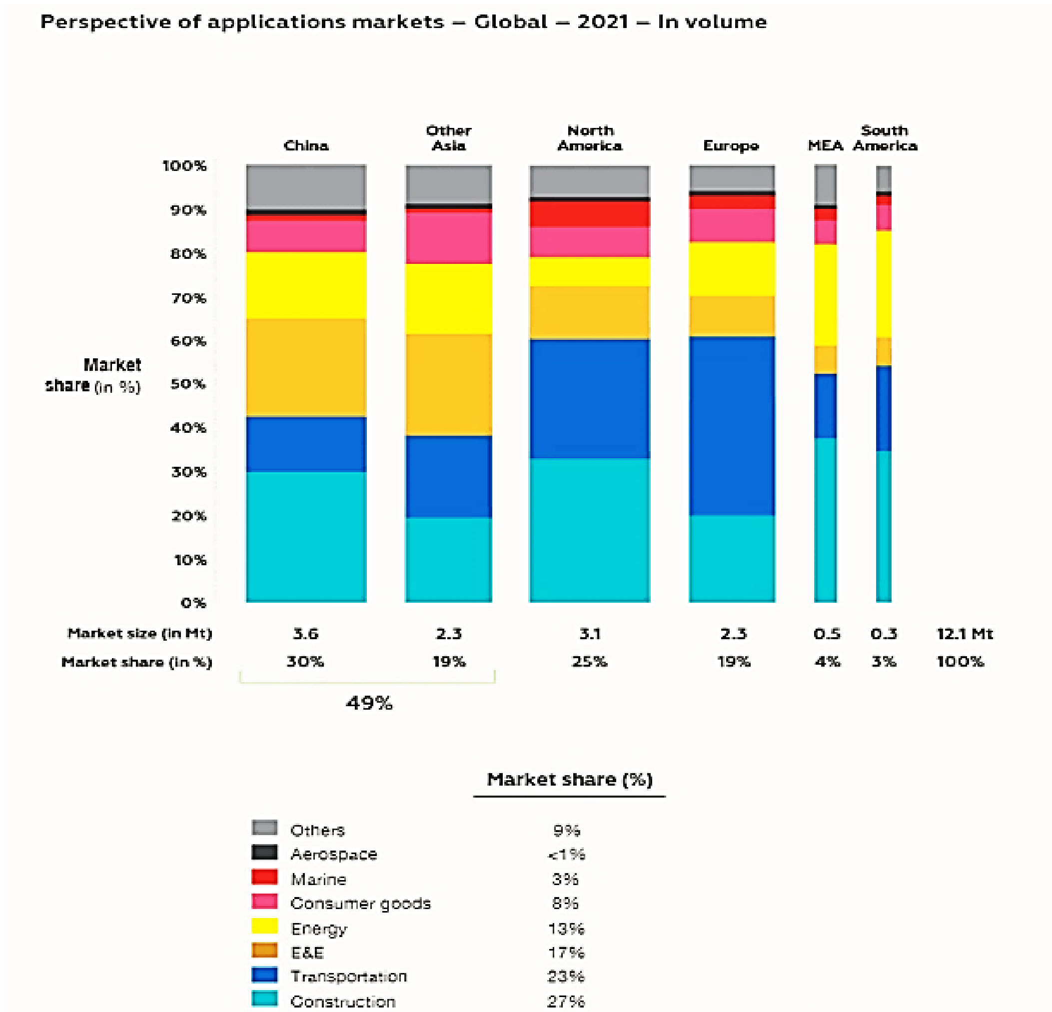

Figure 6.13.2 Perspective of applications markets (Global) in volume-2021 [11]

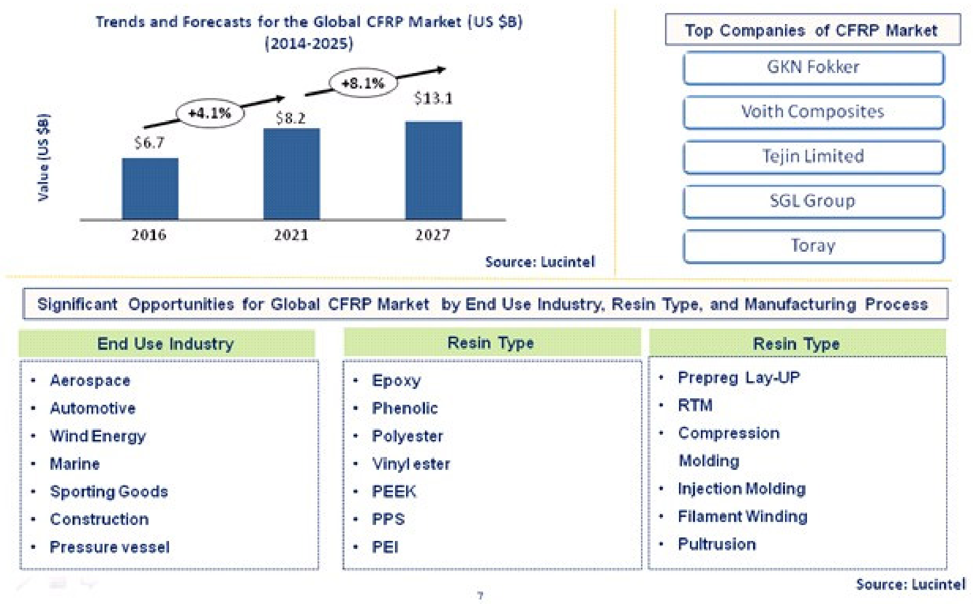

Figure 6.13.3 Trends and forecasts for the global CFRP market in US Billion USD (2014-2025) [10]

The future of the global composites market looks promising with opportunities in transportation, marine, wind energy, aerospace, pipe & tank, construction, electrical & electronics, and consumer goods. The global composite materials market is expected to reach an estimated $59.8 billion by 2027, with a CAGR of 5.8% from 2021 to 2027. The global composite end product market is expected to reach an estimated $158.7 billion by 2027. The major drivers for growth in this market are increasing demand for (i) lightweight materials in the aerospace & defense and automotive industries; (ii) corrosion- and- chemical-resistant materials' demand in the construction and pipe & tank industries; (iii) electrical resistivity and high flame-retardant materials' demand in the electrical and electronics industry.

For GFRP composites, the fastest-growing market is the Asia Pacific. Over the next five years, the market for GFRP composites is anticipated to develop at the quickest rate in the Asia Pacific region. The growing use of GFRP composites across various sectors, including wind energy, building & infrastructure, electrical & electronics, and transportation, is driving this market in the Asia Pacific region. China dominates the Asia Pacific GFRP composites market.

In 2016, the wind energy sector in China had the most installations of wind turbines, resulting in a capacity increase of 23,328 MW.

6.14 Indian Scenario

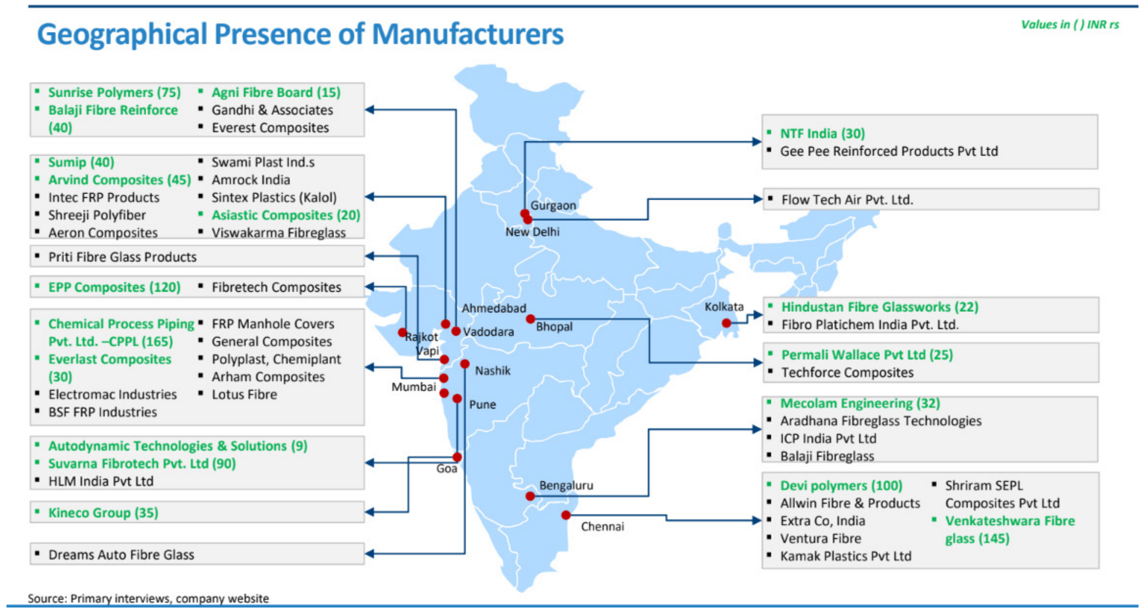

Figure 6.14.1 Geographical presence of manufacturers in India [18]

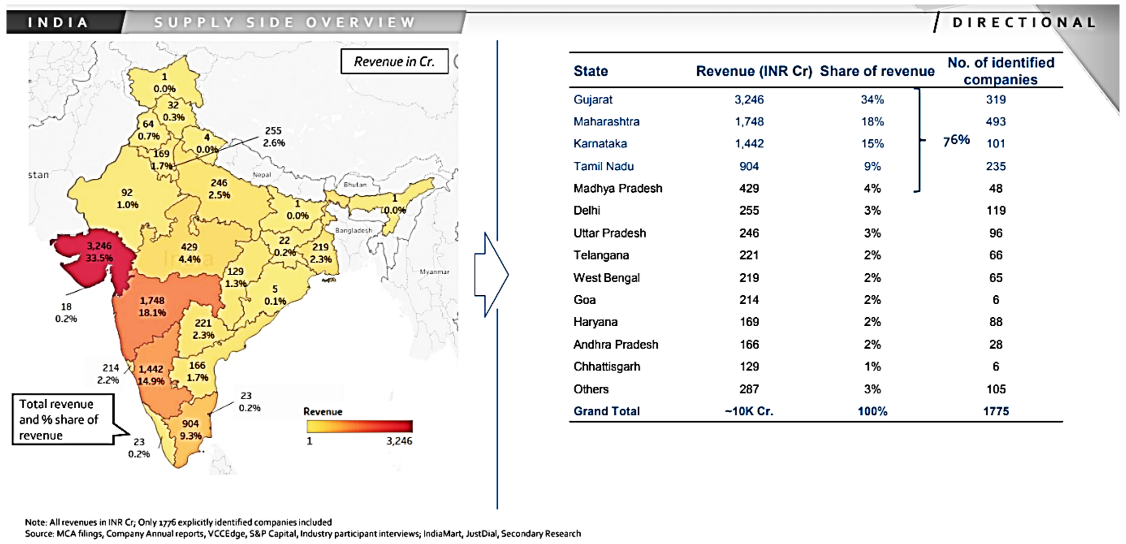

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Figure 6.14.2 Share of revenue of identified companies in India (state wise) [18]

Table 5. Major Indian players in the composite industry [18]

Indian companies	Main composites products/expertise	Main countries for export
Devi Polymers Pvt. Ltd., Chennai (Est. 1975)	Glass-reinforced plastic (GRP)/sheet moulding compound (SMC) panel-type water tanks; GRP/SMC enclosures; GRP/SMC canopies; OEM products	Middle East, the USA, the UK, South Africa, etc
Composite Designs & Technology (CDT)/Epsilon Composite Solutions (ECS), Pune (Est. 1999)	Product design and process engineering of composites, for infrastructure, architectural, transportation, marine, and corrosion applications	Singapore, Bahrain, Japan, the UK
Gandhi and Associates, Vadodara (Est. 1972)	Anti-corrosion applications, process equipment	Middle East, Europe
Industrial & Commercial Enterprises, Pune (Est. 1988)	Skylights and structural fiber-reinforced plastic (FRP)	
Kamak Plastics Pvt. Ltd., Chennai (Est. 1964)	Wind turbine covers, textile machinery covers, cabins, motor covers, tanks, etc	
Kineco Pvt. Ltd., Goa	Design and manufacture of composite products for rail, automotive, and petrochemical industries, including pipes, boats, underground storage tank	The USA, Europe
Mechemco Industries, Mumbai	Manufacture of polyester resins, vinyl ester resins, speciality resins and gel-coats, and also resins for solid surface and casting	

Naptha Resins and Chemicals Pvt. Ltd., Bangalore (Est.1974)	Unsaturated polyester resin, vinyl esters, phenolic resins, polyester pigments, gel-coats, filled resins, putty resins	
NTF (India) Pvt. Ltd., Manesar (Est. 1996)	Interior and exterior panels for automotive, railway coaches, locomotives, wind turbines, commercial vehicles, farm equipment, and construction equipment. Expertise in resin transfer moulding (RTM), Light RTM, vacuum-assisted RTM, MIT, SMC, hand lay-up, and thermoplastic composites. Polyurethane composites by RRIM. Painting of thermoset and thermoplastic parts with polyurethane paints solvent and water based. In-house engineering capability from product concept to production	The USA, Italy, Japan, Spain
Resadh Group: Satyen Polymers; Marketing International, Mumbai	manufacturer of unsaturated polyester resins, all grades; Marketing International distributor for Magnum Venus Plastech, exporter of designed/fabricated equipment and turnkey projects	The UAE, Saudi Arabia
Sintex Industries Ltd.,	Kalol Roto moulding, blow moulding, thermoforming, SMC, pultrusion, prefabs, BT shelters, hand lay-up, FRP underground tanks, etc	The USA, Australia, Africa, Middle East, Europe

6.15 India Value Chain v/s Global Value Chain

The state-of-the-art technology, modern research, industry applications, international production, and diversified investments in strategic locations are increasingly organized within the composite industry's so-called global value chains (GVCs). Globalization motivates companies to restructure their operations internationally through outsourcing and offshoring activities. The past decades have witnessed a strong trend toward the global dispersion of value chain activities such as modern technology adoption, design, production, marketing, distribution and backward integration. M&A and consolidation have also been key growth strategies of some of the prominent composite players across the globe. This has helped companies not only to build competitive advantages but also build significant cost advantages over their competitors. In recent times, the GVCs in the composite industries have been adversely affected by the global supply chain disruptions due to the pandemic.

The value chain in India is in its nascent stage and needs a comprehensive approach to become at par with the global composite industry. The Indian composite industry is growing at a CAGR of 10% and is expected to grow at the same pace over the next 10 years.

In India, fiber reinforced plastics (FRP) were first manufactured in 1962. Subsequently, many other players started manufacturing FRP composite products through a hand lay-up process. The high cost of raw materials, lack of availability of many essential materials because of import restrictions and the lack of mechanized production methods affected the production of composites in large volumes. As a result, the Indian composite industry could not compete with steel, aluminium or timber. Improvements in volume growth only started in early 2000 due to the globalization of the Indian economy. The total composite production was about 75,000 tons in 2004-05, and it had risen to 1,10,000 tons in 2005-06. The Rs 6,000 crore Indian composites industry in 2010 has been on an upswing. The strong growth was spurred by the increasing demand for pipes and tanks, renewable energy (wind & solar energy), mass transit, automotive, trucks, and power. The Indian composite industry today has grown to ~14000 crs. However, the composite value chain is hugely dependent on global supplies. The other critical parts of the value chain, like developed supply chain, modern technology, governmental focus, developed industry bodies, qualified human resources, design capabilities, modern manufacturing methods, and favourable regulatory bodies, are essential for developing the Indian composite industry.

The Global supply chain is very reliant on Chinese manufacturers for glass fiber supply. It is estimated that Jushi, Taishan and CPIC hold around 60% of the global market share for glass fiber. Due to the current negative sentiments toward Chinese materials, it can affect the pricing due higher tariffs. Jushi had recently backed out from a project to build the largest glass fiber manufacturing plant in Maharashtra after site finalization. When it comes to carbon fiber, similar to the Chinese stronghold in glass, Japan has a stronghold in carbon fiber. A disruption in relation with Japan can adversely impact the carbon import of any country.

The logistics cost have been very volatile, post-covid and Panama issues. This creates substantial pricing issues, especially for countries like India that depend on imports for more than 50% of glass fiber requirements.

Last year, the resin shortage, however, had a different genesis. It was triggered primarily by Winter Storm Uri that afflicted US states in mid-February 2021. This fast-moving front brought sudden and unusual freezing temperatures as far south as Houston, Texas, which is home to a variety of petroleum-based processing facilities, including oil refineries and polymer manufacturing plants. The cold temperatures disrupted water, natural gas and electricity supply, thus forcing the facility owners to declare force majeure and shut down.

Hexion (Columbus, Ohio, US), which produces bisphenol-A (BPA, a key ingredient of epoxy) at two facilities in Texas, was forced to cease operations. Similarly, epoxy specialist Olin (Clayton, Miss., US) was forced to shut down all operations at its facilities in Texas, Louisiana, Mississippi and Alabama. These and other shutdowns were consequential not just for the epoxy supply chain but the vinyl ester supply chain as well, which requires epoxy.

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SABIC, which has a considerable share in Styrene Monomer production (a key component of resin production in India), has caused many problems during the last couple of years due to drastic price increases.

In April 2021, Composites World and Gardner Intelligence conducted a supply chain survey to understand the difficulties in material shortage. Key highlights were:

1. When asked which resin systems have been more difficult than usual to acquire in the last three months, 49% of those who responded listed vinyl ester; 49% also listed polyester and 36% listed epoxy.
2. When asked which fiber types have been more difficult than usual to acquire in the last three months, 78% of those who responded listed glass fiber; 39% listed carbon fiber.
3. The fiber formats in the shortest supply, according to respondents, were roving (52%), chopped fiber (43%), woven fabrics (35%) and UD tape (20%).
4. The core material in the shortest supply was foam (53%).

The reasons cited for the disruptions were balanced: Shipping delays, not weather-related (56%), high demand (48%), and inclement weather (36%). In India, per capita consumption of composites has recently increased from 0.25 kg in 2012 to about 0.3 kg now, albeit this is still far less than 2.5 kg in China and 11 kg in the USA. Due to the market's expansion, which is fueled by upgradation in the mode of mass transportation, electrical and electronic equipment, infrastructure, building, and construction, this 0.3 kg was made possible. The usage of FRP composites, which was 3.6 lakh tonnes in 2018, is predicted to increase quickly to 4.9 lakh tonnes by 2022. According to projections made using data from the previous five years, the consumption of FRP would increase from a CAGR of 5.9% between 2013 & 2018 to a CAGR of 8.2% between 2019 & 2023.

Table 6. Indian key composite manufacturers and their turnover [18]

Parameters	Very Large	Large	Medium	Small
Universe of Players	• 6	• 10	• 25-30	• 50-55
Turnover (INR. Crs)	• 75-165	• <75-20	• <20-2	• <2
Key Players	• Chemical Process Piping Pvt. Ltd., Venkateshwara Fibreglass, EPP Composites, Devi Polymers, Sunrise Polymers, Suvarna Fibrotech	• Arvind Composites, Sumip Composites, NTF India, Kineco Group, Balaji Fiber, Everlast Composites, Hindustan Fiberglass, Permali Wallace, Asiastic Composite, etc.	• Autodynamic Technology, Technoforce, Asiastic Composite, Gandhi & Associates, Mecolam Engg, etc.	• Shreeji Polyfiber, Aradhna Fiberglass, Kamak Plastic, Fibertech India, Amrock India, ICP India, Priti Fibre glass, Divya Inc etc.
Service offerings	• Offer a wide range of product • Provide customised products as per client's requirement • R&D facility for product innovation • Provide complete solution from designing to component supply to installation and AMC • Select players have raw material(Fibreglass) production tie up with foreign companies e.g.: Arvind PD composites, Kineco Kaman, etc.		• Offering products for specific segments • Low customisation and innovation level • Provide solution from component supply to installation and AMC	• Mainly into supply of industri products like Tanks, Vessels, pipes and fittings, PCE, canopies, electrical products • Provide standard solutions • Mainly into component suppl
Operation Overview	• Most of the players are present across segment • Strong tie-ups with EPC consultants and contractors • Pan India presence through branch offices and dealer network • Also into exports		• Presence in specific customer segment • Pan India presence through Sales person and dealers • Mainly cater to domestic market	• Mainly into allied business of conventional products • Regional focus
Raw material	• 5%-25% raw material are imported • Key fiberglass suppliers- 3B Fibreglass, Owens Corning, Shogo International, BMY Industries, Saint Gobain, Hi Tech Fibre glass, U.P. Twiga, Asahi Glass		• Barring 2-3 players, all are procuring indigenously	• 100% raw material procurement indigenously

Source: Primary interviews, Feedback Analysis

Please Note: Above mentioned turnover and other details are w.r.t. to FRP products only

Key export to countries like the USA, European Countries, Indonesia, Thailand, Bangladesh, the Middle East, South Africa, etc.

a. For the past 2 years there has been a decline in export orders mainly from the European market
b. High import level for FRP Pultruded products

6.16 Gap Areas and How to Fill Those Gap Areas

- For Glass Fiber, only Owens Corning have a larger production facility in India. OC Indian facility has a capacity of 100,000 MT. India, a country with more than double OC local capacity requirement, is heavily reliant on importing glass fiber. Tariffs and Logistics costs can impact such a dynamic scenario. India should focus immediately on attracting one more fiberglass producer to set up manufacturing in India.

- The heavy reliance on SABIC and other limited suppliers for the monomer used in our Resin production has weakened India. We should work our better bilateral relationships to ensure monomer availability and price stability. Another option is to impact the oil producers in India (IOCL, Reliance etc.) to focus intensely on integrating monomer refining & resin production.

- Carbon fiber product manufacturing is weakened due to a lack of local carbon fiber production. In addition to a few domestic companies planning to enter carbon fiber production, the government can provide an attractive offer to an existing international company to set up their new carbon fiber production facility in India

- **Technology**

India lacks the technology to develop the raw materials for FRP composites. Also, the number of patents in India on FRP composites is far below that of some developed countries. With regard to technology development, a considerable amount of research and development is necessary both at the laboratory and industrial levels.

- **Government Support**

Government should begin campaigns on publicizing FRP composites to concerned stakeholders and educating them on the benefits of FRP composites. Bearing in mind the initial high cost and the long-term economic benefits of FRP composites, applicators of FRP composites should be treated with a subsidy of some form. Furthermore, funding for research and development should be substantially increased to develop science and technology and ensure that further technological developments stay within India. Efforts should be put towards establishing integrated manufacturing units of FRP composites, maybe initially seeking technical support from globally recognized players. Further, to enlighten young minds to pursue their career in FRP composites, fundamental courses should be floated in diploma, graduation and post-graduation curricula across various departments in various institutes/universities.

- **Collaboration**

Collaboration between industries and institutes within the shadow of the government should ensure holistic integration of all FRP composite developmental activities. Several workshops and academic programs should be offered on various platforms across different geographical locations to promote FRP-related activities in small and medium-scale industries. In India, many industries, such as TATA steel, have already begun collaborating with institutes like NIT Rourkela for efficient knowledge transfer to convert research into full-fledged technology.

- **Infrastructure**

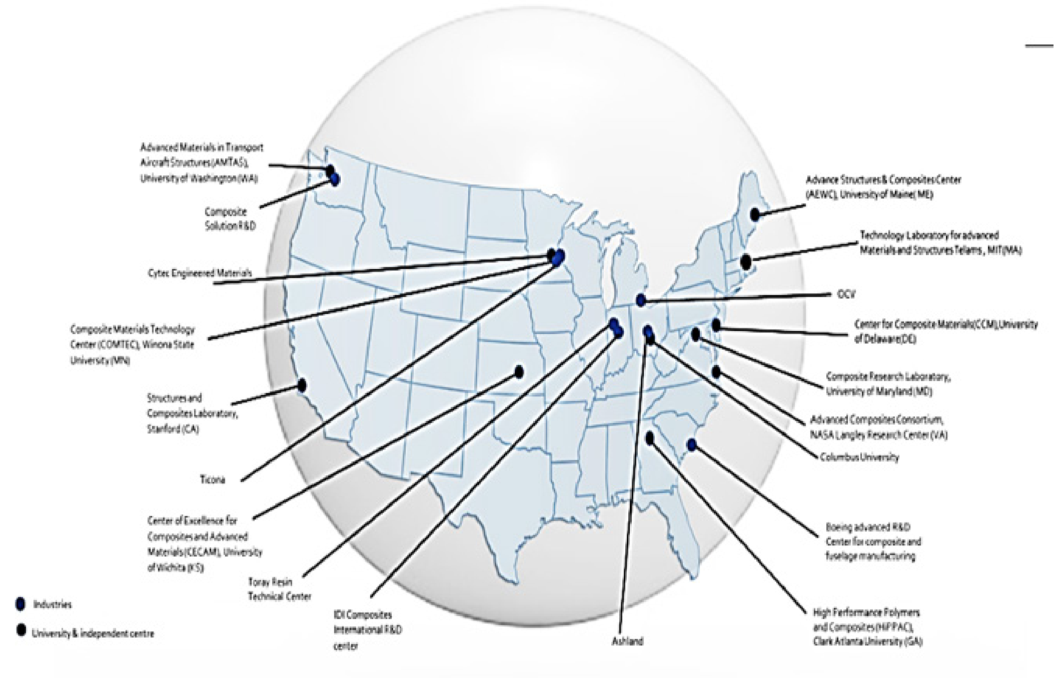

Figure 6.16.1 Overview of main composite material research centers in the US. [11]

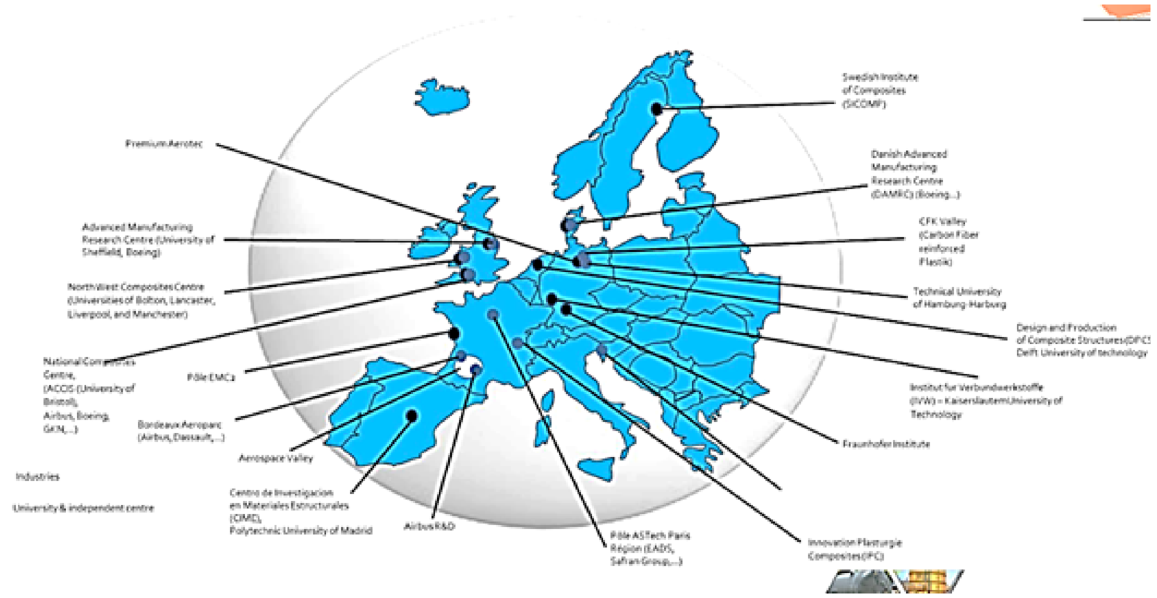

Figure 6.16.2 Overview of main composite material research centers in Europe. [11]

There is a dire need for infrastructural development to fuel the growth of FRP composites in India. Almost all significant institutes worldwide have a center or department dedicated to researching and developing composite materials. In India, such number of dedicated established centers for composite materials is less than 5, whereas in the US (Figure 17) and European nations (Figure 18), it is a considerable amount.

Supply Chain

A major issue plaguing the development of FRP composites in India is the unavailability of quality raw materials. The composite industry is dependent on foreign raw materials producers. There are Indian producers too. However, their products may be of inferior quality.

6.17 Role of Stakeholders

The buoyant domestic demand for Composites provides a driving impetus for all stakeholders within the value chain; – Raw Materials suppliers, and End Component fabricators, thus boosting employment prospects as well. Currently, the Indian Composites Industry is poised to provide a lucrative opportunity to the International Composites Community, and the still untapped markets will provide a platform for investments, both FII & DII.

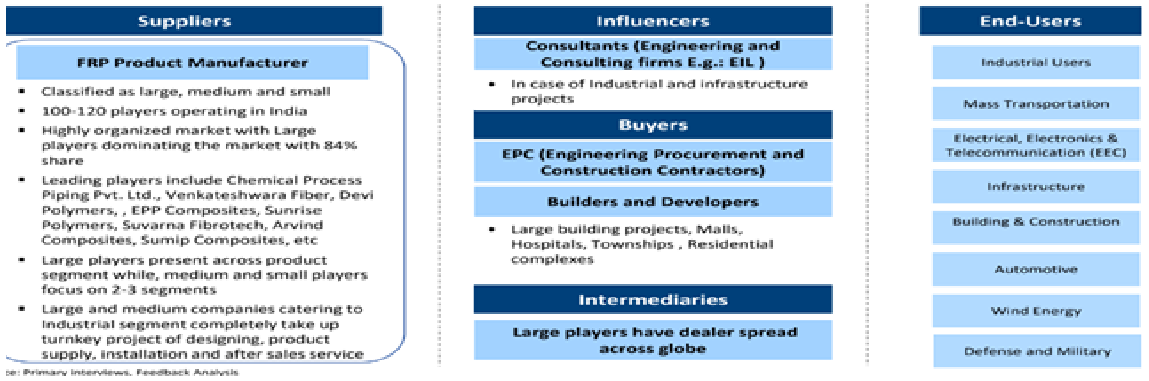

Figure 6.17.13 Industry value chain and role of key stakeholders [18]

The Composites Industry is cyclical, depending on the country's economic growth and business cycles. It is dominated by institutional business (B2B and B2G), which is correlated with applications, sectors, technology and the country's overall GDP growth.

The Indian Composites Industries have witnessed single-digit growth in recent years and is expected to grow at a Compounded Annual Growth Rate (CAGR) of 8.2% in the next five years. The per capita consumption of composites in India is around 0.3 kg, against 2.5 kg in China and 11 kg in the US.

The major driver for the Indian composites market growth is the 'Make in India' Initiative. The rise in demand for Composite Components is imminent for renewable energy, oil & gas, mass transportation, electrical and electronics, chemical industry, infrastructure, building and construction (smart cities development, etc.) and water management.

6.18 Recommendations and Concluding Remarks

- **Small Term**

The immediate use of fibrous polymeric materials may be in water/sewage pipelines, electric poles, portable cabins, and toilets as a lot of modernization projects are being executed in various cities in the Smart city mission. Due to lightweight, ease of installation, non-corrosive nature and attractive aesthetics, FRP composites in this regard may become successful and thus give confidence in the industries to expand their business to a higher scale. Polymer composites from renewable resources have also received increased attention over the past few years due to environmental matters and the fast depletion of traditional energy resources. In plastic waste disposal and recycling, fiber-reinforced plastic as a subclass of plastics has given rise to a number of disputes and disquiets. FRP is logically expected to gain environmental sensitivity as new, eco-friendlier matrices such as bioplastics and UV-degradable plastic come to the fore.

- **Medium Term**

It can be stated with certainty that the FRP industries have a bright future ahead of them due to the constantly expanding Indian automobile market and the progressive shift within that market from heavy, inefficient metallic structures to lighter, more fuel-efficient FRP structures. In India, the mass transportation sector accounted for 20.5% of all composite component usage in 2018. However, several auto manufacturing firms on a global scale have already realized the enormous potential of FRP.

The market for FRP composites in the railroad industry is very diverse, starting with uses for FRP windows, FRP window frames, composite brake blocks for railroad coaches, ceiling panels, side panels, and lavatory panels, lavatory modules for LHB coaches, a set of FRP components for LHB chair car coaches, entrance doors of coaches, FRP gear cases for locomotives, railway cross ties/ sleepers, and railway platforms.

The defense sector is one of the most critical dimensions of any country, irrespective of its GDP. Continuous modernization of defense technology is a matter of compulsion and thus needs to be looked at very seriously. FRP composites in this regard may be widely employed to make bullet-proof jackets composed of synthetic fabrics, FRP helmets, FRP safety masks, and rifle components for the country's security and safety. In India in 2018, this industry consumed 6.3% of FRP composites, and this percentage will soon rise. FRP composites are essential in creating impact-resistant armored vehicles, tanks, and desert patrol vehicles to improve the safety of personnel under challenging environments. Convenient Bridge Armoured vehicles made of FRP composites can be used since they can quickly and rapidly navigate the pathways to access distant places. The same is true for patrol and rescue boats.

The INS Vikramaditya is a Kiev-class aircraft carrier modified for national service. The frigate, whose superstructure is entirely built of composite materials, is constructed using the idea of stealth technology. India currently only has two active aircraft carriers, unlike the US's eleven. India is projected to increase its fleet size, which would require a significant number of raw materials, which should expand the raw materials market.

The area of renewable energy also significantly influences composites growth in India. One of the most popular future alternatives is wind energy, which is now being used in many parts of the world and plans to increase its generation manifold in the future. As a result, a wide range of prospects for the use of FRP in wind turbines become available, an area that the major FRP industry players can take advantage of.

The market for FRP-based wind turbines found in India has one of the most incredible installed wind power producing capacities. By adding 4148 MW of capacity in 2017, which was 20% higher than in 2016, wind energy in India reached a significant milestone. The capacity of the wind energy sector will rise along with it, resulting in growth for the Indian composite industry. India currently has the fourth position in total installed wind energy capacity (35 GW), whereas China currently holds the first spot with 221 GW, followed by the USA and Germany.

A significant contribution may be made to meeting general environmental goals for resource conservation and CO2 emissions reduction in rail freight transportation by considering the growth factor "Lightweight." This will increase the benefits of rail as a means of transportation for the environment. Currently, standard rail freight wagons utilize just a third as much energy per ton-km as typical vehicles. Effects that are to be achieved from using modern composite materials in the railway wagons are:

a. better corrosion protection of the wagon elements,
b. easier unloading of the wagon in winter conditions (no freezing of the cargo to the floor and sides),
c. reduction of the weight of the wagon while its payload increases, easier management of the freight wagons during exploitation.

- **Long Term**

The aerospace industry is expanding quickly, and many businesses are turning to composites to fulfill both Indian and global needs. A lot of businesses outsource their production to the USA and Europe. Long-term FRP market growth has enormous potential in India, one of the world's fastest-growing aviation industries. When fully established and equipped to meet internal demands, the domestic aerospace industry has the potential to be a single, significant driver of market growth for the Indian FRP industry. However, several major players in the aircraft industry, including Boeing, Airbus, and Textron, have already switched from using conventional components to FRP-based ones. Boat building was the first maritime application of FRP composite soon after World War II. FRP composites are also used to construct ship hulls. Radomes, microwave applications, and communication antennas are part of the telecom industry's burgeoning field. In 2018, 6.4% of the total FRP volume was consumed by the Indian telecom sector. Since radars are a crucial structural component of aircraft and warships, there will be a sizable market for radomes in the years to come.
Concluding Remarks
The following conclusions can be made based on the technological and commercial aspects of fiber-reinforced polymer composites:

a. FRP composites are the cutting-edge materials of the century, offering a broad range of tailorability while providing the ideal mix of structural property requirements, including strength, modulus, density, fatigue, and corrosion resistance.
b. FRP composites have many uses in the building, marine, aerospace, and defense industries.
c. India is a rapidly expanding nation, thus, there is a massive need for strategic composites development and manufacturing to meet the current demand.

d. Under different smart city programs, a number of projects might be undertaken, including the production of FRP water and oil pipes, water tanks, electric poles, portable toilets, and cottages. Furthermore, medium- and long-term projects may be concentrated on significant usage of FRPs in bridges, trains, autos, and other structures due to incremental increases in manufacturing capacity and maturity in managing more extensive projects.
e. Industries also need to take care of the manufacture of raw materials like various types of sophisticated fibers and polymers in order to create a competitive FRP market in India. Recycling and reusing abandoned and end-of-life industrial and commercial products is another technological challenge that requires extreme caution to be handled.
f. Given the anticipated large-scale demand for these materials in nearly all structural sectors, with a particular focus on transportation and construction, numerous small- and large-scale enterprises in India have launched numerous attempts and campaigns to enter the FRP market.
g. A specific interdisciplinary course on "Composite materials" should be offered in technical institutions to diploma, degree, and post-graduate students in light of the anticipated future market. Establishing research-focused laboratories in diverse locations, maybe incorporating academics and industry, is also necessary in this regard.

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CHAPTER 7:

RECYCLING MATERIALS

7.1 Recycling Materials and their Background

E-waste

As per Central Pollution Control Board (CPCB), E-waste Management Rules charted in the year 2016, the e-waste [1] is defined as "electrical and electronic equipment (EEE), whole or in part, discarded as waste by consumers (individual or bulk) as well as rejects from manufacturing, refurbishment, and repair processes". The primary identification of e-waste is that used EEE is no longer fit for its originally intended use and is ready to be discarded. All the end-of-life equipment which we intend to discard for the purposes of dismantling and recycling will fall under the category of e-waste.

- ***Importance of e-waste recycling:***

1. Environment protection: E-waste possess the elements that causes the enovironmental and health issues such as lead, cadmium, mercury, hexavalent chromium, polychlorinated bi-phenyls (PCBs), brominated flame retardants (BFR), etc. This happens during unsafe handling or storing of the e-waste. So, it is necessary to keep the e-waste away from the landfills
2. Saving natural resources and making values: E-waste can be considered as the secondary raw materials for elements/compounds such as plastics, iron, glass, aluminum, copper, and precious metals such as silver, gold, platinum, and palladium and lead, cadmium, mercury, etc. Extraction of these metal values from e-waste would delay the exhaustion of primary sources or ore deposits of various precious, and rare earth elements and platinum group of metals (PGMs). And, this will increase the affordability as the process technologies are less energy intensive, less polluting the environment and simple and economical.

- ***Global Value chain***

Market size:

The amount of e-waste generated across the globe [2] is increasing at an alarming rate: In 2019, 54 million tons of e-waste was generated. This was estimated as 21 % raise compared to last five years [3], and the Asia Pacific region alone is responsible for 24.9 million tons. This increasing rate is 3 times faster than the world population rate. With this rate the global e-waste is expected to exceed 70 million tons in 2030 [4]. Fig.1 presents the expected generation of global e-waste [5].

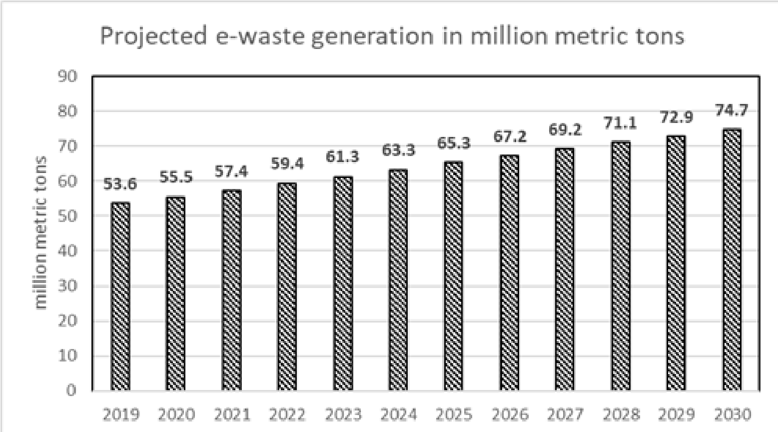


Figure 4: Global e-waste generation forecast till 2030 [5]

Key producers:

S. No.:	Companies	Metric tons	Revenue in USD	Technology
1	MBA Polymers, Inc:	17.5		1. Seperation from metallic parts melting, 2. Cleaning, and 3. Blending and compounding
2	Enviro-Hub Holdings Ltd:		26.2 million as on 2018	
3	Global Electric Electronic Processing Inc:			Recycles the waste through collection, sorting, dismantling the parts of WEEE (Waste Electrical and Electronic Equipment) and sells it outside
4	Aurubis AG:		1.12 billion as on 2018	Pyrometallurgy followed by hydrometallurgy for Cu refining and precious metal recovery-with proper gas cleaning plant
5	Boliden		5.1 billion as on 2018	Pyrometallurgy cum hydrometallurgy
6	Sims Metal Management Ltd:	10 million	6.64 billion as on 2018	
7	Umicore:	2,50,000	3.8 billion as on 2018	Has pyrometellurgy cum hydrometallurgy route – with properly addressing the waste management
8	Dowa			
9	Aurus, russia			

Table 7: Key ewaste recycling companies in the world [6, 7]

- ***E-waste management in the world:***

Figure 2 demonstrates the e-waste management system in a few countries such as switzerland, Italy, and Japan wherein it can be observed that the collection methods are streamlined properly with proper legislation. Also, the producers are held responsible for collecting and recycling the e-waste.

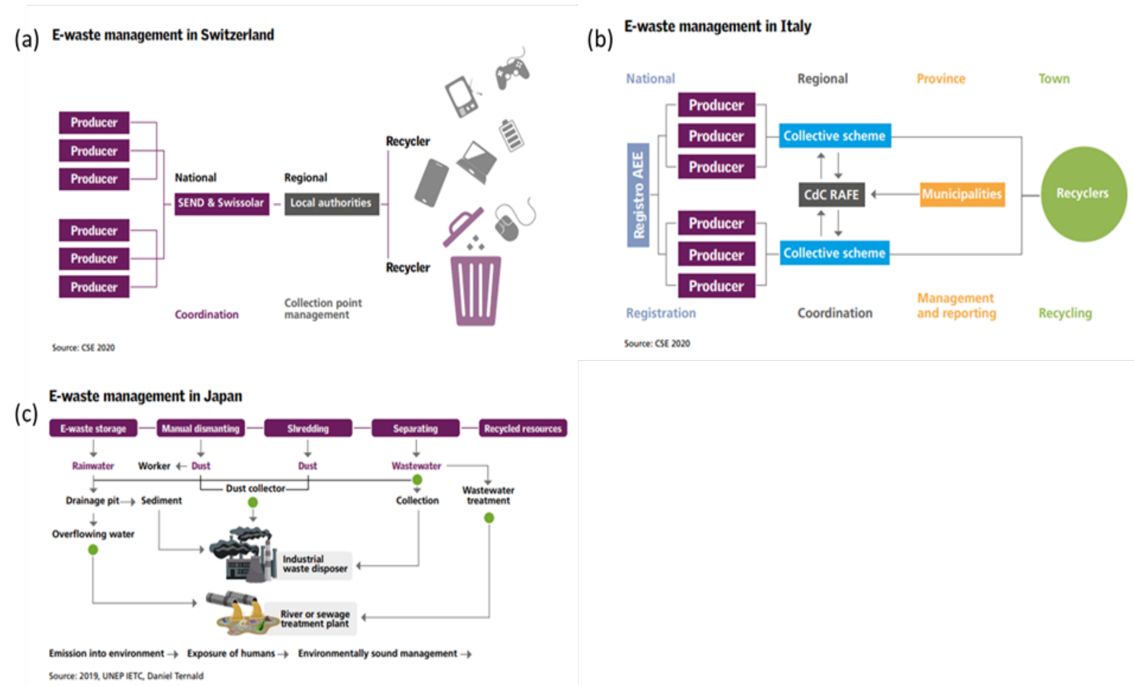


Figure 5: E-waste collectio management chain in switerland (a), Italy (b), and Japan (c) [8] – make this graph big and one page and add legislation of the market

- ***Indian Scenario:***

India is one of the top fives countries with contribution to e-waste generation of 3.23 million metric tons which is equivalent to 2.4 kg per capita [8]. Among these generation quantity only 1 % is collected for recycling (Table 8) which is very less when compared with other countries. And in future, it is forecasted to touch 25.8 million metric tons in 2035 (Figure 6). Among the totat e-waste generated, Maharastra alone contributes for 13.9 % which is followed by Tamil Nadu, Andra Pradesh, Uttar Pradesh, and others (Figure 7). The generated wastes are collected and processed for e-waste recycling. The ideal collection flow of e-waste is shown in the Figure 8 with leakages superimposed on it. The leakages lead to the processing of e-waste through informal sectors exising within the country. The major challenges in formal collection of e-waste is the poor reach of formal collectors and the unwillingness of consumers to take ownership of the waste produced by them. Procesing e-waste consists of two stages (Figure 6 (a)) which are (1) prepprosseing, and (2) end processing. In this prepprossesing, mechanical disintegeration of e-waste material takes place.

In end processing stage, metallurgical processes are expected to take place. As an example, for PCBs either combination of pyro cum hydrometallurgical (Figure 6 (b)) processes are followed or hydrometallurgical (Figure 6 (c)) process followed. Among these processes, hydrometallurgical alone process is cheap and easy to carry out. However, it has its own disadvantages such as low recovery rate with environmental pollution by fluid used for processing. This environemtal pollution is inevitable when the procesing liquids are disposed improperly to environment. This is is exactly expected to be happening in the informal processing centers in India who is receiving leaked e-waste material. For detailed understanding Table 3 can be refered. There are 400-450 authorised recyclers are in India till date

Table 8: Top five contries in e-waste generation with its collection rate in 2019 [8]

	rank in e-waste generation	market (kg/capita)	generation (kg/capita)	collection rate (per cent)
1	China	13.3	7.2	16
2	USA	25.3	21	15
3	India	5.8	2.4	1
4	Japan	21.3	20.4	22
5	Germany	18.2	19.4	52

Source: CSE 2020

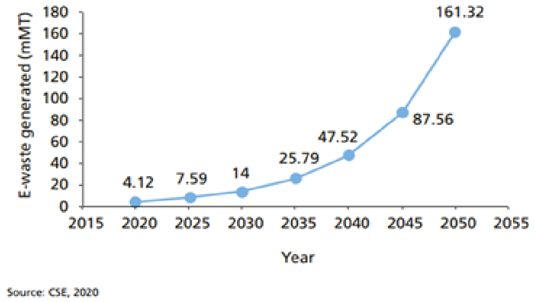


Figure 6: Projected e-waste generation in India [8] comparte Figure 1 and 3

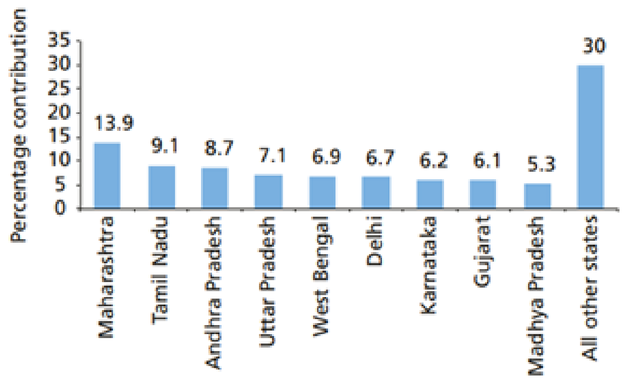


Figure 7: Annual e-waste generation by Indian states in 2018 [8]

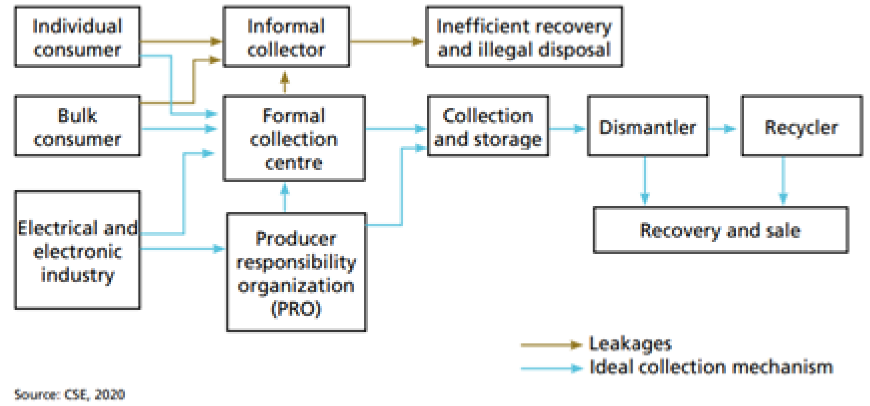


Figure 8: Ideal collection flow of e-waste materials for recycling with leakages represented from individual and bulk customers to informal sectors [8]

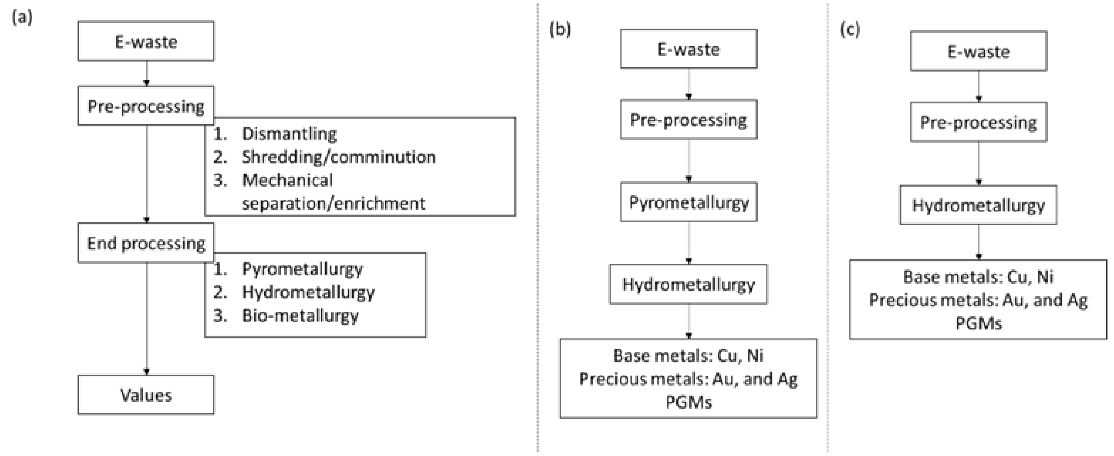


Figure 9: Stages involved in the e-waste processing (a) [9], pyro cum hydro route is a globally followed method by well-known companies across the world for PCBs (b), and hydrometallurgy route followed for PCBs (c)

Table 9: Practises followed by formal and informal sectors [8]

Parameter	Informal sector	Formal sector
Percentage of e-waste processed	90	10
General practices of e-waste processing	Rudimentary methods: Incineration, breaking, dismantling, dumping, etc.	Industrial recycling and dismantling using technically advanced methods
Current stakeholders	Dealers or retailers, unorganized recycling sector (local pawn shops, recyclers, dismantlers, etc.) contractual labour, localized vendors (kabadis)	Government, consumers, retailers, industries or organizations, registered processing units, NGOs and manufacturers
Binding laws	Not bound by any laws or regulations	Environmental laws, E-waste (Management) Rules, labour laws, etc.
Major functions	Collection, disassembly, extraction and dumping	Disassembly, extraction, recycling, treatment and segregation

Source: ASSOCHAM and NEC Technologies report, Electrical and Electronics manufacturing in India 2018

- ***Challenges and way-forward for e-waste recycling in India:***

Currently 66% of the world population living in 67 countries are covered by their respective national e-waste management lawGlobal e-waste Monitor 2017). Europe has the most developed legislation. Countries in Northern America, Eastern Asia, and Southern Asia have well developed e-waste recycling and collection mechanism. National e-waste legislation is completely absent in several regions of the world. (Global e-Waste Monitor 2017). The People's Republic of China and India - the most populous countries in Asia currently have e-waste rules, whereas only a handful of countries in Africa have enacted e-waste-specific policies and legislations.

For regulating the collection and processing of the e-waste generated in India, series of legislation is passed by the government since 1986. The recent legislation passed by the Indian government is in the year 2016, amended subsequently in 2018, with the following objectives:
(1) To implement Extended Producer Responsibility (EPR), laying emphasis on producers' responsibility for environmentally sound management of e-waste, even at the postconsumer stage, (2) To promote the establishment of an efficient e-waste collection mechanism, through take-back systems and buy back, (3) To promote environmentally sound technologies through authorized dismantlers and recyclers, (4) To minimize illegal recycling and recovery operations in the informal sector, (5) To reduce the use of hazardous substances in the manufacture of EEE.

Though the legislations are existing, still the gap is found in the followings:
(1) inventorization e-waste, (2) improper regularisation in importing of e-waste, (3) stringent monitoring on EPR target fulfilling, (4) monitoring of informal sectors for reducing the leakage e-waste materials and its employee's health status, (5) improving awareness among consumers about e-waste, (6) improper gas cleaning processes from the pyrometallurgical process units, (7) efficiency of e-waste recycling processes: extraction of values from the waste with the maximum extraction efficiency – should be compared with the benchmark process efficiency, (8) throwing the processed liquids in the environment, and (9) health and safety of workers in the informal sectors.

7.2 Aluminum

As per International Aluminum Institute (IAI), nearly 75 % of the produced aluminum since 1880 has been in the service now. Till now, 900 million tons of aluminum has been produced [9]. Aluminum is an ideal metal that can be recycled many times without losing its quality. All aluminum used in cars, buildings, aircraft, etc. can be recycled. Also, the aluminum beverage cans are being recycled at far higher rates than the materials such as glass, plastic bottles, other composite containers.
The role of aluminium sector will be critical, as India advances to meet its economic growth targets. With India's growing economic might, it should be able to produce enough high-quality metal to ensure self-reliance in its defence and critical infrastructure needs to avoid global volatility in supply and prices.
Globally Aluminium is produced through two routes: (1) the primary route which involved conversion of ores to aluminium, and (2) the secondary route which is a recycling route involves aluminium production from its scrap (machining swarf, dross, end-of-life aluminium products, etc).

- ***Advantage of aluminium recycling [9]:***

a. To produce 1 tonne of aluminium through the primary route requires 4 tonnes of bauxite, 0.415 tonnes of carbon, and 13460 kWh of energy. However, to produce aluminium through secondary route, 95 % of energy required is saved which makes this route advantageous over primary route. This varies based on the type of scrap, fluxes requirement, and recycling technology.

b. In addition to the energy savings, nearly 94 % savings on CO2 equivalent can be achieved for aluminium recycling.

c. Capital cost involved for this steel recycling units is 1/10th of capital cost requirement for primary aluminium production.

d. And the produced aluminium through this recycling route can be sold 10-15 % cheaper than the aluminium produced through the primary route.

The production of Al through the secondary route is shown Figure 7 (a). Aluminium recycling which at present holds for one third of aluminium consumption has been in place since commercialization of primary aluminium products. During this recycling, aluminium quality will not be deteriorated which enables recycling aluminium for more than one time. 100 % of the scrap arising from the manufacturing of aluminium products can be recycled.

- ***Importance of Al recycling:***

In parallel to the economic growth, the Indian aluminium industry is expected to grow in both primary metal, and downstream sectors. Aluminium consumption in India was 3.3 million tonnes in 2015-16 has grown to 5.3 million tonnes in 2020-21. Aluminium consumption per capita which is 2.4 kg for India is much lesser than the global average of 11 kg per capita (Figure 8). This shows the potential demand that is highly likely in the future. Also, the government initiatives such as Make in India, smart cities, housing for all, rural electrification, freight corridors, bullet trains, EVs (Electric Vehicles), etc will have heavy requirement of aluminium. Another crucial point that needs to be noted here is only 2-5 % of loss was noticed during secondary aluminium production. This is as per a study that was carried out by Delft University, The Netherlands.
Further aluminium recycling industry is categorized into two (Figure 7 (a) & (b)): (1) re-melters and (2) refiners. Here, re-melters produce wrought alloys by carefully choosing the scrap grades. Refiners primarily use scrap produced through primary aluminium production to dilute impurities.

- ***Global scenario on secondary aluminium production:***

This secondary aluminium alloys produced is categorized into to which are wrought alloys and cast alloys [10]. The global secondary aluminium alloy market is estimated to garner a revenue of USD 63245 Million by the end of 2030 by growing at a CAGR (Compound Annual Growth Rate) of 4.90% over the forecast period, i.e., 2021 – 2030. Moreover, in the year 2020, the market registered a revenue of USD 39198.54 Million. As per International Aluminium Institute (IAI), in 2016, 17 million tonnes of the aluminium scrap were accrued worldwide. This number was expected to touch 21 million tonnes in 2020 which is more than 1/3rd of primary aluminium production. At present, around 20 % of aluminium demand is covered through old scrap.
According to estimates by the International Aluminium Institute (IAI), in 2016 around 17 million tons of aluminium old scrap were accrued worldwide. This number will increase to around 21 million tons in 2020, according to IAI. This corresponds to a share of more than a third of today's global output of primary aluminium. Today, around 20 % of our aluminium demand worldwide is covered by old scrap. Table: 4 shows the global secondary aluminium produced from the countries/continent like China, Japan, US, and Europe.

Global secondary aluminium production (in '000 tons)

	Country	2011	2012	2013	2014	2015	2016	2017	2018
1	China	4400	4830	5270	5650	5780	6200	6200	6250
2	Japan	142	137	143	143	149	151	159	156
3	US	3110	3370	3420	3560	3560	3580	3640	3700
4	Europe	2591	2543	2543	2640	2637	2645	2859	2855

Table 10: Production of secondary aluminium (in kT) in China, Japan, US, and Europe [9]

Following are the prominent industry leaders in the secondary aluminium alloy market [10]:

a. Century Metal Recycling Limited,
b. Kawashima Co., Ltd.,
c. Daiki Aluminium Industry Co., Ltd.,
d. Allocco Recycling, Ltd.,
e. Superior Aluminium Alloys,
f. LLC,
g. Metal Exchange Corporation,
h. Keiaisha Co., Ltd.,
i. Shin Wen Ching Metal Enterprise., Ltd.,
j. Namo Alloys Pvt. Ltd.,
k. Sunalco Industries Pvt. Ltd.

Aluminium recycling treats all category of aluminium scrap collected or imported from end-to-end products and process scrap. Globally Recyling rates are higher in transport cum building sectors and beverage sectors which are 90 and 70 %, respectively. Transportation is the major field of application worldwide due to its low density and reducing greenhouse gas emission. Among the various countries currently do aluminium recycling, US is the world most resource abundant secondary recovery site because of its long history of aluminium production and consumption.

- ***Indian scenario:***

Figures 9 & 10 (a) shows the secondary aluminium production quantities since 2015. Between 2015 and 2020 secondary aluminium demand has grown to 1.3 million tonnes from 0.86 million tonnes with CAGR of 9-10 %. The secondary aluminium which will be expected to in 2 million tonnes demand in the year 2023, accounts for 30 % of India's overall aluminium consumption of 3.7 million tonnes. Figure 10 (b) shows the major sector that consumes secondary aluminium in India. Auto sector is major sector that drives secondary aluminium market between 2015 and 2020 with contribution of ~57 and ~40 %, respectively. As the scrap generation is extremely limited in India, more than 3/4th of the scrap falls into the imported category (Figure 12, and 13 (a)). Few leading producers of secondary aluminium products in India are as follows [11]:

a. Associated Aluminium India Pvt Ltd,
b. Century Metal Recycling Ltd,

c. Century N F Castings,
d. Indo Alusys Industries,
e. Minex Metallurgical Company,
f. Namo Alloys Pvt Ltd and
g. Sunalco Alloys

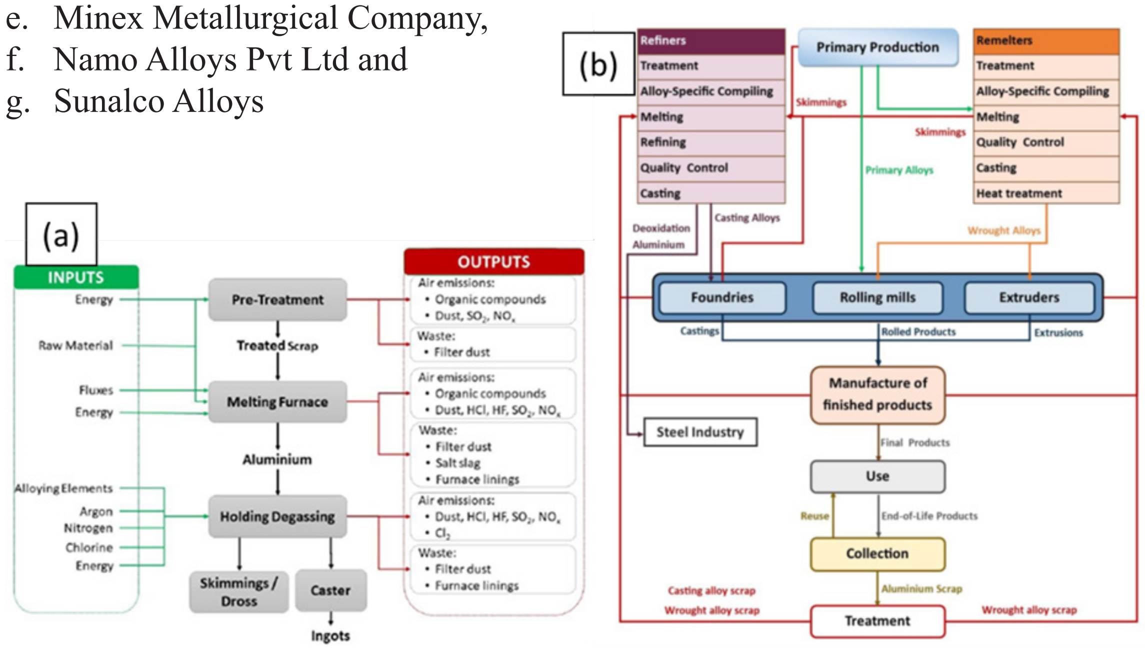


Figure 10 (a): Secondary aluminium production route, and (b) Overall process flow of Aluminium from primary processing to secondary processing

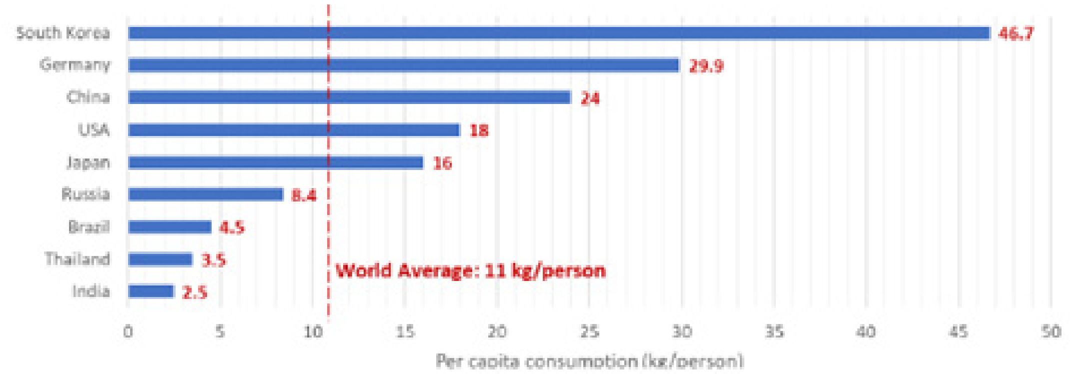


Figure 11: Per capita consumption of aluminium in 2017

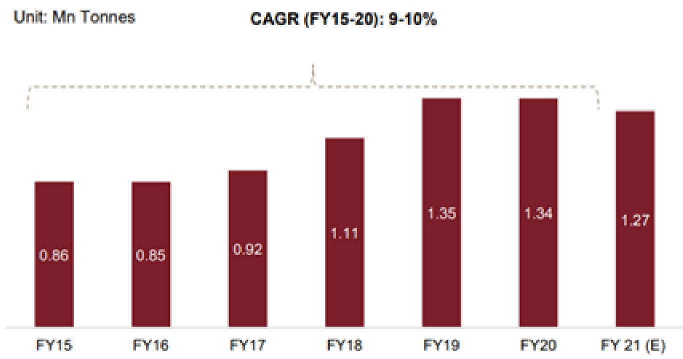


Figure 12: Secondary aluminium processing till 2020 [12]

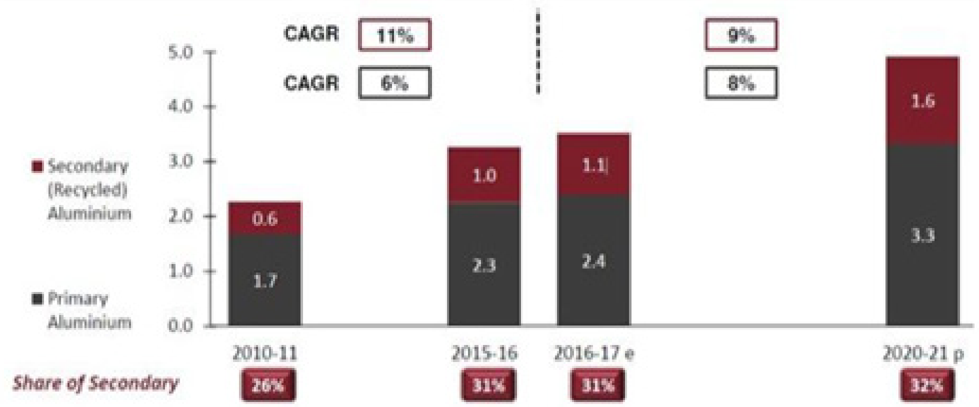
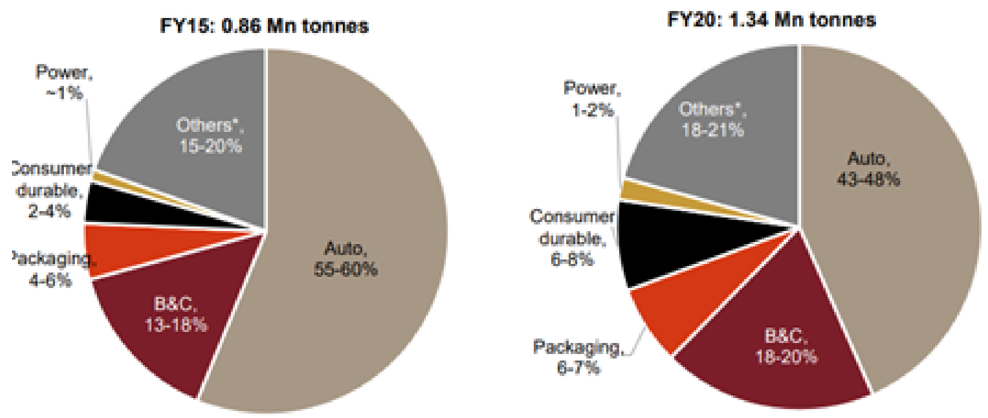


Figure 13: Share of primary and secondary aluminium in India [13]



Others include defence,aerospace,machinery and equipment amongst others: B&C: Building and construction

Figure 14: Application of secondary aluminium in various sectors [12]

Figure 15: Aluminium scrap imports from 2015 to 2019 in india [14]

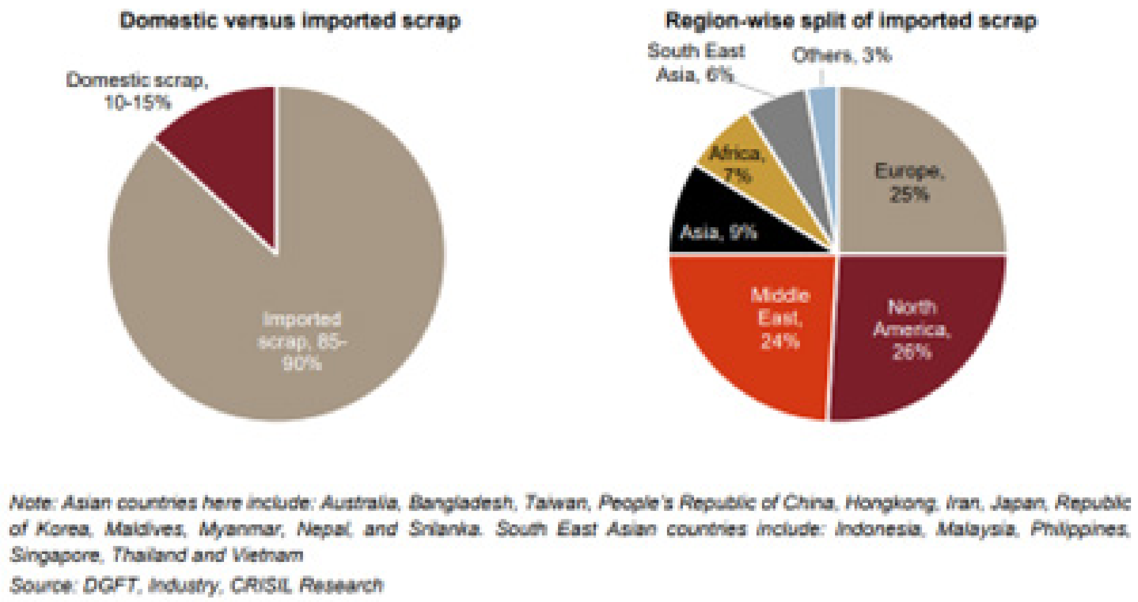


Figure 16: Imported aluminium scrap in india (a), and regionwide in the world (b) [12]

- ***Gaps and Concerns:***

In overall, Figure 14 compares the Indian scenario with global scenario on the aluminum recycling.
Scrap sorting and processing need to be carried out efficiently; otherwise, unwanted impurities may find a path to reach recycled aluminum Additional efforts need to be taken to separate aluminum scrap from the end-of-life products. To achieve this, for achieving this, proper collection and separation system should be in place
As mentioned earlier, more than 3/4th of the scrap is imported – this is again due to lack of collection, segregation, and processing facilities in India. Also, higher end-of-life items from electrical sector is expected to be causing this.
Mechanization of aluminum sorting process and, adding beneficiation techniques such as eddy current separator, magnetic separator, shaking table, gravity separator, heavy media separation etc. would make the scrap recycling are major steps
Post-consumer scrap recycling must be done separately and carefully as it carries impurities and coatings on the scrap.
Development of standards for sustainability and environment are crucial for recycling as it reduces the environmental footprint compared with primary aluminum production. Also, guidelines from competitive authorities need to be setup for equipment for complying with pollution norms.

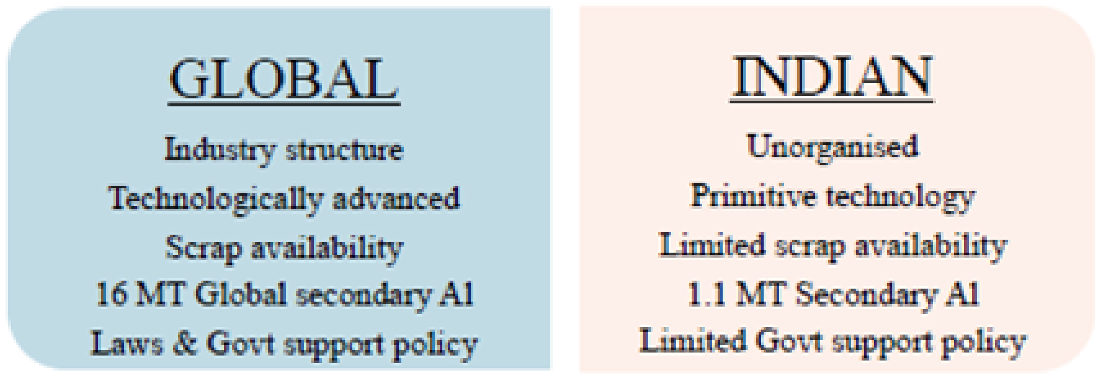


Figure 17: Comparison between global and Indian secondary scrap recycling processes [9]

In India, quality standards for recycled aluminum need to be established as few re-melters are expected to be selling their products with lower standards [9]. In the aluminum scrap recycling sector, only 10 % of the market is unorganized. This includes utensil manufacturers and some extruders.

7.3 Concrete or Construction & Demolition (C&D) Waste

- ***Importance:***

The construction sector, which is one of the top contributors to the GDP, is consistently increasing the inflow of investment. The real estate industry is expected to grow with the CAGR of 6.6 % between 2019 and 2028 [16]. The construction sector is expected to account for 15 % in the GDP of 2025 [17].
Building material requirement for the new building and infrastructure projects have been so high when compared to the past and is expected to rise soon. So, the building material sector itself is an enormous economy. The National Skill Development Corporation (NSDC) estimates the share of construction cost in any project is around 40-60 % [18].
A crisis for building raw material in future is inevitable in near future. Table 1 talks about the criticality of availability of the building materials.

Parameter / Resources	Scarcity	Cost	Environmental impact	Embodied energy	Supply risk	Lack of recyclability	Conflict of use
Soil	**	*	***	***	**	***	***
Iron	*	***	***	***	*	*	*
Limestone	*	**	***	***	*	***	**
Sand	***	**	***	**	***	***	*
Stone (aggregate)	**	**	***	***	**	***	**
Copper	*	**	***	***	*	*	*
Bauxite (aluminium)	*	**	***	***	*	*	*
Petroleum (PVC)	*	**	***	***	*	*	*
Silica (glass)	*	**	***	**	*	*	*
Wood	**	***	***	**	**	*	*

(Legend: * is Low, ** is Medium, *** is High)

Table 11: Criticality of availability of building material

A rise in housing crisis in the country leads to the scarcity for availability of the construction materials. Rise in demand coupled with shortage of aggregates will end up in raising of the cost of construction of the building. A study by Venkatesh M. Paranthaman, a construction industry expert, found that resources like human power and materials make the highest contribution—about 24 per cent—to delays in construction projects [19].

In addition to these, there are environmental problems associated with waste that are occupying ground or open space which are as follows: (1) Urban flooding, (2) Destruction of waterbodies, (3) Groundwater pollution, (4) Clogging landfills, (5) Hindering municipal waste management, (6) Degradation of open spaces, (7) Obstructing mobility, and (8) Dust pollution. So, the strong requirement for recycling of C&D is expected. With this, importance of recycling of C&D wastes can be explained.

- ***World scenario:***

Globally, 2.01 billion tons of solid waste is generated. Half of these quantity is attributed to C&D waste material according to the report of world bank [20]. It is estimated that C&D waste generated in Europe is more than 850 million tonnes [21] and 530 million tonnes in the United States in 2014 [18]. China had generated about 1000 million tons of C&D waste in 2013 [22]. As per the research, it has been set up that reusing C&D waste as a practical alternative to naturally sourced building material. The developed countries such as EU and Singapore have reported C&D waste recycling over 90 % [23]. Following are aggregate making companies using recycled concrete in USA: (1) Lehigh Cement, (2) Vulcan Materials Company, (European Union) and USA have already capitalized this opportunity.

Their recycling rates falls somewhere between 70 and 80 %. Some EU members and Singapore have reported C&D waste recycling over 90 % [23]. Following are aggregate making companies using recycled concrete in USA: (1) Lehigh Cement, (2) Vulcan Materials Company, (3) FERMA CORP, (4) LafargeHolcim, (5) Top Grade Site Management, LLC, (6) Delta Sand & Gravel Co., (7) CEMEX S.A.B. de C.V., (8) Southern Crushed Concrete, (9) Big City Crushed Concrete and (10) Independence Recycling of Florida. Figure 18 explains about the process flow followed in Taiwan C&D waste recycling process. And this process flow may be expected to follow in the worldwide.

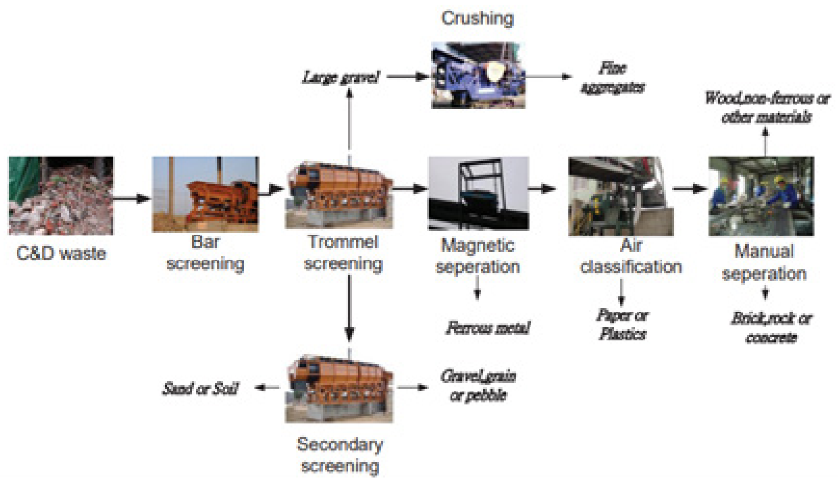


Figure 18: Process flow for C&D waste recycling in Taiwan

- ***Indian scenario:***

a. As per estimation, India generates around 150 million tonnes (Table 12) of C&D wastes, annually. However, this may be 3 to 5 times more. The composition of C&D waste is shown in the Table 13
b. India has recycling capacity for about 6,500 tonnes per day which is 1.3 % of total C&D waste generated
c. Till 2017, 53 cities were expected to install recycling facility; however, only 13 cities met the expectation (Table 14)
d. Technical ability on what and how to segregate different category of C&D waste is still question mark. Also, inconsistencies seen on characterisation methods and quantification of generated C&D waste. In addition to these, methods have not been upgraded to advent the new-age construction materials
e. Delhi 4th phase is the only good practice in the country

f. Architects design for waste mitigate handles 33 % of the waste generation
g. The government scheme, “Swachh Survekshan 2021” gives more prominence and scoring points to action on C&D waste. However, this needs to push right design for segregation, collection, recycling, and reuse.
h. Role of informal sector: Existence of a fast-growing informal economy in and around C&D waste in cities. C&D waste is an easily available material at almost zero cost is informally used for multiple purposes, many of which have multiple environmentally associated problems. Table 15 shows how the C&D waste is processed by informal sector situated in the cities.

Year	Authority/Institute	Estimate (million tonnes)
2000	Ministry of Urban Development	10–12
2001	Technology Information, Forecasting and Assessment Council, Department of Science and Technology	12–15
2010	Ministry of Environment and Forest	10–12
2013	Centre for Science and Environment	530
2014	Ministry of Urban Development	No estimates
2015	Ministry of Urban Development	10–12
2015	Development Alternative and GIZ	750
2016	Ministry of Environment, Forest and Climate Change	530
2017	Building Material and Technology Promotion Council	150

Source: Compiled by CSE

Table 12: C&D waste generation quantity in India since 2000

Waste sub-streams	As per Technology Information Forecasting and Assessment Council (TIFAC), 2001 (India)	As per MCD survey, 2004 (Delhi)	As per survey by Infrastructure Leasing & Financial Services (IL&FS) Ecosmart, 2005 (Delhi)	As per study by University of Florida, 2009 (India)	As per Coimbatore City Municipal Corporation survey, 2015 (Coimbatore)
Soil/sand, gravel	36	43	31	35	49
Bitumen	2	0	0	2	0
Metals	5	0	0.4	5	4
Masonry/brick	31	15	59	30	19
Concrete	23	35	0	25	23
Wood	2	0	1.5	2	2
Others	1	7	7.6	1	3

Source: Compiled by CSE

Table 13: Composition of C&D waste

City	Place	Capacity (TPD)	Operation status
Delhi	Burari	2,000	Operational
	Mundka	150	Operational
	Shastri Park	500	Operational
Noida	Sector 80	150	Operational
Gurugram	Basai	300	Operational
Ghaziabad	Ghaziabad	150	Operational
Thane	Daighar	300	Operational
Indore	Devguradia	100	Operational
Hyderabad	Jeetimedla	300	Operational
Bengaluru	Chikkajala*	1,000	Operational
	Kannur	750	Operational
Ahmedawbad	Gyaspur Pirana	1,000	Operational
Tirupati	Tukivakam village	150	Operational
Vijayawada	Vijayawada	200	Operational
Chandigarh	Industrial Area Phase 1	150	Operational
Surat	Surat	300	Operational

Note: * Privately owned and operated
Source: Compiled by CSE

Table 14: India C&D waste recycling plants

Recovered building material	Process	End product, economics and recycling hotspots
Steel rebars	Hammering during demolition renders some steel bars deformed and twisted, converting them into scrap	**Used for:** Steel scrap is melted down in foundries (furnaces) and cast into blocks of iron and steel **Where:** Foundries in Ghaziabad and Sikandrabad in UP, and Gobindgarh in Punjab **Rate:** Sold at Rs 22-23 per kg by the contractor
	Steel bars that can be retrieved relatively straight and without deformation are rolled into new shapes	**Used for:** In rolling mills, rebars of adequate length are passed between two rolling cylinders to give them a new shape, e.g. iron railings and steel hinges for doors can be made from rebars **Where:** Rolling mills in Ghaziabad, Muzaffarnagar, Badaun, Bareilly and Bijnor **Rate:** Bars of diameters of 10 mm, 12 mm, 16 mm, 20 mm, 25 mm and 32 mm, and lengths greater than 1.2 m or 1.5 m are sold at Rs 25-26 per kg
	Steel bars that can be retrieved relatively straight and without deformation are also utilized in construction	**Used for:** Steel bars with diameters of 8 mm, 10 mm and 12 mm, and lengths of about 1.2 m or 3 m are used in construction by lower-income groups **Where:** In Ghaziabad, the market is in Jassipura. In Delhi, the markets are in Ghazipur and Sonia Vihar **Rate:** Sold at Rs 30 per kg
Doors and windows	Door, windows and frames are taken out before the actual demolition takes place	**Used for:** Doors, windows and frames are bought by merchants, refurbished and sold **Where:** The markets are in Kalindi Kunj (Delhi), Khoda colony (Noida), Shahberi (Ghaziabad), Muradnagar (Ghaziabad) and Hapur **Rate:** Based on the type of wood (or steel), size and quality, doors are sold for Rs 2,000-3,500 per unit. Windows prices are Rs 1,000-2,000 per unit
Red bricks	Approximately 50 per cent of the bricks can be salvaged and reused	**Used for:** Salvaged bricks are utilized in construction by lower-income groups **Where:** These bricks are usually transported directly from a demolition site to a construction site **Rate:** Demolition contractors sell them at Rs 2-2.50 per unit
Bathroom fittings	Bathroom fitting are dismantled before the demolition begins	**Used for:** Bathroom fittings are usually made up of brass (> 70 per cent), an alloy of copper and zinc, and various other metals and alloys. They are melted down in foundries and cast into brass or copper blocks **Where:** Mandoli in Delhi has foundries that melt copper **Rate:** Bulk rate of Rs 200 per kg, copper sells at Rs 300-350 per kg and brass at Rs 380 per kg
Electric fixtures and wirings	Electric fixtures and wirings are dismantled before the demolition begins	**Used for:** Electric fixtures usually contain copper, brass, aluminium and some other metals. Wires are recycled for copper and plastic. Metals are salvaged and sent to foundries **Where:** Merchants dealing with electric fixtures and wires set shop in Chawri Bazar and Jama Masjid areas. Wires are recycled in Yamuna Pushta in Delhi **Rate:** Copper: Rs 300-350 and PVC: Rs 10-15 per kg
Glass	Glass from buildings is salvaged and sold in the second-hand market	**Used for:** Most common types of glass are clear glass and toughened glass. Clear glass can be reshaped and fetches more money. Toughened glass, on the other hand, cannot be resized easily and sells at lower rates **Where:** Merchants in Paharganj, Delhi **Rate:** Clear glass: Rs 12-16 per kg and toughened glass at Rs 4-5 per kg
Debris	Demolition of a building generates a lot of debris, composed of roller-compacted concrete (RCC), bricks, plaster, tiles, glass, etc.	**Used for:** Debris management is generally assigned by demolishers to transporters. There is a lot of demand for debris in backfilling, elevation improvement and road construction. Debris is also dumped illegally on roadsides, and in drains, waterbodies, municipal solid waste dhalaos, etc. **Where:** Across the city as per the demand **Rates:** Transporters charge Rs 600-700 per pickup by a trolley of 2-3 cu. m capacity and Rs 3,500 per pickup by a dumper of 19-20 cu. m. Dumping charges are Rs 500-1,000 per turn
	Pure RCC from demolition is diverted to crushing	**Used for:** Pure RCC waste is obtained free of charge by merchants, crushed and mixed with sand **Where:** Crushers are located in Noida and Gurugram **Rates:** Pickup is free of cost. Some demolition contractors prefer this type of waste as they do not have to spend anything on transportation

Table 15: C&D waste processing through informal sector

- ***Gap identification and way forward:***

a. Need robust estimation of C&D waste:
b. Characterization of the C&D waste is necessary for the management plan.
c. Land identification for collection and recycling
d. Set up transportation system for collection and transfer of C&D waste
e. Strengthen the governance framework
f. Responsibility of the construction Industry
g. Learn from global practices
h. Build confidence in recycled products for quicker uptake
i. Integrate Informal sector in C&D waste management and disposal
j. Mandatory adoption of demolition management strategies
k. Mandate on-site construction waste management during construction phase
l. Advance application of tools for end-of-life waste recovery, recycling, and circularity
m. Waste management in infrastructure projects
n. Dust control in construction projects

7.4 Steel Recycling

- ***Importance:***

The production steel from primary sources or ore requires multiple steps involves cumulative energy input of 15-24 GJ/t. Major part of this requirement is satisfied through coal as a major reducer/fuel. In contrast with this, the steel recycling requires only 1.3-6.0 GJ/t [24]. Entire energy requirement for this can be satisfied through the electricity which can be produced through renewable energy. At present, nearly 40 % of the total steel produced is through secondary steel making or steel scrap recycling. The production of steel through secondary steel making not only saves energy but also it paves way for reduction in CO2 emission [25].

Though iron is the sixth abundant element, very less fraction of it is available concentrated fit for beneficiation and extraction. Ultimately recoverable resource (URR) is 346 GT iron ore with the demand of 3.0 Gt/year in 2011. This requirement is keep raising and it will reach the peak value of 4.5 Gt/year in the mid of the century [26]. Also, the steel recycling having the following purposes: (1) it promotes circular economy in the steel sector, (2) it decongests Indian cities, (3)

- ***Global scenario***

The global steel recycling market size was calculated to be around USD 353.30 billion in 2020. And this value is estimated to reach USD 563.92 billion by 2026 [27]. The global market for steel scrap recycling was 574.1 million metric tons in the year 2020, and it is expected to grow to 784.8 million metric tons by 2027 with a CAGR of 4.6 % between 2020 and 2027.

Scraps usually split into three categories: (1) home scrap, (2) old or end of life scrap, (2) industrial scrap. Scrap recycling process follows the following steps worldwide: (1) collection and sorting, (2) separation using magnetic, eddy current, and heavy media, (3) dezincing and detinning, and (4) shredding or balling, (5) EAF (Electric Arc Furnace) melting, (6) casting, (7) forming, (8) final product.Based on the requirement and type of scrap, this procedure can be varied. For e.g., galvanised steel requires dezincing process, other normal steel scrap do not require this step.

- ***Indian Scenario [28]:***

At present, India's scrap market is unorganised and most of it are manual operation with safety and environmental concerns. In general, apart from usage of scrap in the primary route of steel making in BOFs (Basic Oxygen Furnace) (Basic Oxygen Furnace), scrap is used to produce long product through EAF/IFs. As on 2019, March, Indian was having 47 EAFs and 1128 Induction furnaces. All these furnaces were depending upon the scrap as a raw material feed. In 2019, 32 million metric tons of steel scrap was used, and it was 11.5 % higher than 2018. Among these quantities, 25 million metric tons of the steel scrap was sourced through local scrap dealers and remaining were imported from China, United States, UAE, Saudi Arabia, Iraq, and other markets.

There is an enough potential to harness this 7 MT of scrap from domestic markets itself. This requires adequate collection centres, dismantling centres shall work in a hub-spoke model and feed to the scrap processing centres. For achieving this target 70 scrap processing centre are needed with 300 collections and dismantling centres with the presumption that 4 collecting and dismantling centres cater to a scrap processing centre. Handling capacity of each of these 70 scrap processing centre is 1 lakh tonnes. This will encourage full-service recycling companies and scrap traders to explore potential export opportunities to the Indian market. In 2020, the UAE and US are the first and second scrap suppliers to India with the market share of 12.4 % and 12.5 %, respectively.

As the Indian government works towards its ambitious plan such as Self-Reliant India or "world's largest steel producer," the requirement of ferrous scrap will increase to 50 to 75 million tons per annum by 2030 (Figure 19). when the production of steel rises to 250 MT, as is envisaged in the National Steel In 2030, when steel production reach 250 – 300 million tons per annum, the requirement of scrap shall rise to 70-80 million tonnes per annum. To achieve this target, India needs about 700 scrap processing centres which will be fed by 2800-3000 collections and dismantling centres spread all over the country.

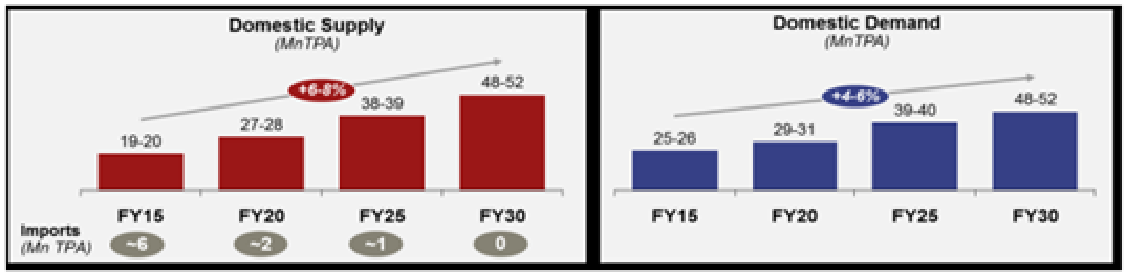


Figure 19: Steel scrap demand and supply projected till 2030 [28]

In addition to these requirements, Zn on the galvannealed steel may affect the EAF/IF processes. This will be avoided by dezincing processes during the recycling stage itself just before feeding into furnaces. Also, a similar process needs to be carried out for tin coating on the steal too. These de-zincing and detinning processes are never being carried out in India, however, other steel recyclers in the world is carrying these processes to remove Zn and Sn from the steel scrap coatings. In addition, Waelz kiln process can be adopted to process Zn in EAF (Electric Arc Furnace) dust.

7.5 Copper

- ***Global supply chain – Key recycling agencies***

Copper Scrap market size is estimated to be worth USD 65950 million in 2022 and is forecast to a readjusted size of USD 84900 million by 2028 with a CAGR of 4.3% during 2022-2028.

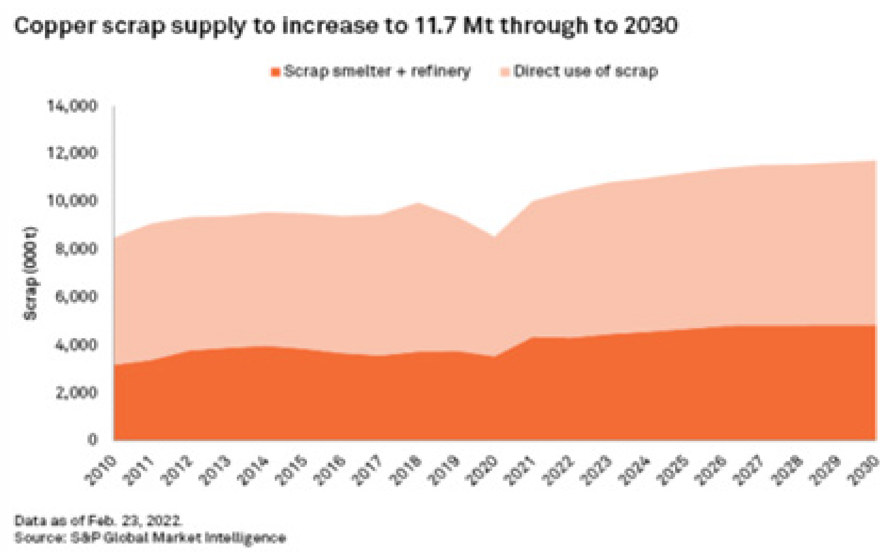


Figure 20: Copper scrap supply - global - with forecast up till 2030 [15]

It is forecast global copper scrap supply — including smelter and refinery feed and directly melted scrap — to rise to 11.7 Mt in 2030 from 10.0 Mt in 2021. Despite the projected increase, the scrap recycling sector faces several challenges that affect both the supply and demand sides of the market and will need to be addressed. China has been the main importer of copper scrap, responsible for around half of the global imports in gross weight. The latest Chinese scrap import rule, set up in 2020, has set the minimum copper content at 94%. This helped boost Chinese imports in 2021, with the gross weight of copper scrap entering China surging 79.5% year over year to 1.7 Mt. Europe exported 2.3 Mt of copper scrap in gross content in 2021. U.S. has been a major exporter of low-grade copper scrap, exporting approximately 919,000 tonnes of copper in gross weight in 2021. The U.S. currently does not have the capacity to treat low-grade scrap, to reduce its carbon footprint and greenhouse gas emissions.
The global demand for copper is expected to continue to grow at a rate of over 3.5% over the next few years and has reached over 18 million tons annually by 2006 [31]. Below table shows forecasted copper demands.

World over forecasted copper demand in 2008.

Area	% demand	Area	% demand
United States	13.4	Oceania	1.0
Western Europe	21.7	Japan	7.1
Africa	0.8	Korean republic	6.3
Other North America	4.2	Taiwan	4.2
Central and South America	2.9	China	22.8
Eastern Europe and CIS	5.7	Other Asia	9.8

Table 16: World over forecasted copper demand in 2008

- ***Indian scenario***

1. It is estimated that between 30% and 40% of the domestic demand in India is met by recycled copper [26]
2. Thus approximately 90,000 MT of copper scrap is imported, and another 60,000 MT is generated from the rejects coming out of the existing copper consuming units [31]
3. India today has a copper smelting capacity of 477,000 tpa with an overpowering contribution from the private sector such as Sterlite Industries Limited (SIL) and Hindalco Industries Limited (the copper business division is known as Birla Copper).
4. Hindalco Industries is doubling the capacity of its Dahej smelter in Gujarat to 500,000 tpa. Sterlite is expanding its Tuticorin smelter in Tamil Nadu from the present 180,000 tpa to 300,000 tpa.
5. By 2020, copper production capacity in India is projected to rise to 1600,000–1800,000 tpa, going by the growth in domestic demand, from 400,000 tonnes in 2003, copper demand are estimated to grow at 8% annually, much higher than world demand growth of 3%.
6. The intensity of copper consumption in India will continue to increase until 2050. Below table (Table 13) shows distribution of copper usage in India [31].

Distribution of copper usage in India.

Sectors	% Consumption[a]	% Consumption[b]
Electrical and telecom	57	32
Transport	7	11
Building and construction	7	35
Consumer durables	6	10
Engineering	9	12
Others	14	–

Table 17: Copper usage in India at various sector

- Below table shows generation rates of diverse types of copper scrap in India. [31]

Generation rates of different types of copper scrap in India.

Scrap type	Generation rate (Gg Cu/year)
Old scrap	
Copper cables	10
Radiators and brass utensils	4
Ship breaking	19
Winding wire	10
Cartridge brass of spent bullets	14
Mixed railway scrap	5
Sub-total	62
New scrap	
Wires and cables	12
Forgings, redrawing, fabrication, and machinery	24
Copper ash, dross, etc.	5
Sub-total	41
Total	103

All figures are in net copper content expressed in Gg Cu/year. Source: ICSG (2003).

Table 18:Different type of copper scrap in India

- ***Technology for copper scrap recycling:***

Based on copper scrap quality, the processing route is adopted. For contaminated copper with quality of 88-99 %, the fire refining cum electrorefining route is chosen. For high quality alloys, induction melting route is chosen, to make the same alloys. For high quality copper, hearth furnace is chosen along with continuous casting to produce pipes and copper sheets.

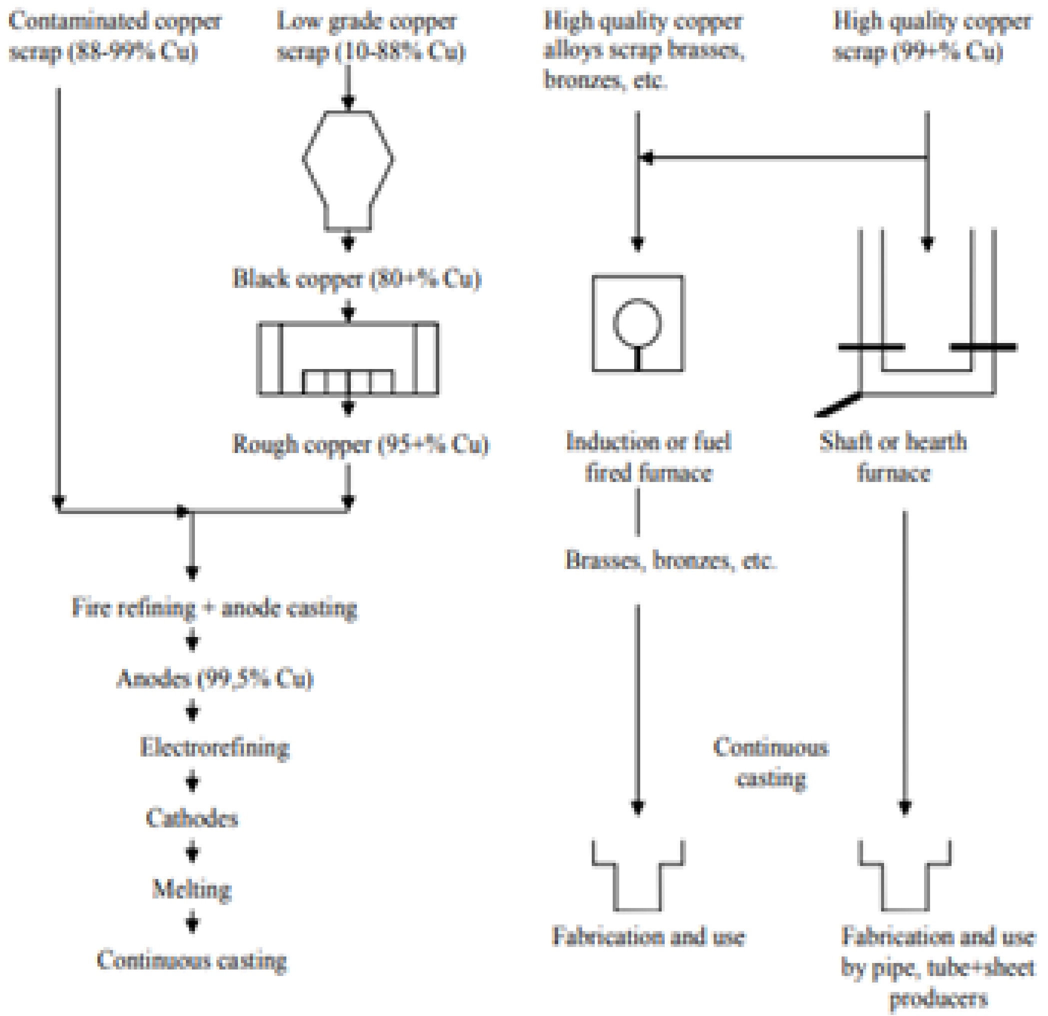


Figure 21: Flow sheet of processes for the recovery of copper and copper alloys from scrap. Low grade scrap is usually smelted in shaft furnaces but also in other furnaces, e.g. electric. [33]

- ***The gap areas and recommendations:***

- Supply side risk
  Monopoly in copper supply makes the market prone for political risk such as domestic political unrest within the mining countries and issues on security and transport accessibility. A 15-day mines closure in Peru and Chile would wipe out 1.5 % global annua Cu supply. India is relying on imported Cu concentrate for their smelters which will be deciding factor for the sustenance of existing capacity and future projects [32]. Steps involved in mitigating the supply-side risk: risk:

  a. Reducing import dependency by finding out other available mines for Cu concentrate supply. As per the Ministry or Mines's annual report, KABIL has signed an MoU with three stat-owned organisations in Argentina, the Fat East Investment and Export agency in Russia. Major industries like Birla group have plans to shift from conventional imports to acquire the mining rights abroad for the raw material and they have already acquired mining rights in two copper mines in Australia.

  b. Incorporating sustainability in midstream and downstream sectors

  c. Investing in R&D initiatives and alternative interventions: For minerals with limited reserves in India such as copper, R&D in mineral processing technologies, and alternative interventions such as advancement in recycling processes are critical.

- Technology gap and corrections
  a. Raise in low grade Cu scrap importing: Many countries have revised their policies and guidelines in copper scrap quality; i.e., imposed higher standards on copper content and purity of the scrap.

  b. Constraints on the demand side of the scrap market: Technical limitations on maximum (17 %) amount of copper scrap used in the copper smelters. To overcome this, an important technological change is necessary to allow more scrap in the smelters. New capacities for secondary smelting can be added to facilitate processing higher processing of copper scrap. E-scrap is used at specialist operations like Boliden AB (publ)'s Ronnskar smelter in Sweden, which has the technology to recover metals, including gold, from mobile phones and circuit boards. U.S.-based Prime Materials Recovery Inc. and Spain's Cunext Group launched a joint venture in February 2021 - produces copper anodes from copper scrap and copper fines. Furthermore, Aurubis will also start construction of a multimetal recycling smelter in Augusta, Ga., in August. This has been planned to commission in 2024. The location of new recycling capacity should be strategically determined, with secondary smelters built close to where scrap is generated — urban areas, major cities, and tech valleys — to minimize transport and reduce the carbon footprint of the process chain.

- Scrap quality is also a factor influencing demand
  Low-grade scrap is typically used in smelters. There are some specialist secondary smelters, but most of the scrap goes to primary smelters where it is charged with the concentrate. High-grade scrap is used in refineries, where it is cast into anodes and then refined. Most wire rod makers need a very-high-quality copper product, with 99% contained copper. Most of the scrap, however, has a lower contained copper content of 94%-96%, which trades at a discount and cannot be used by many wire rod producers. Direct-use scrap is the biggest demand component of copper scrap usage and is supplied by cut-offs from rod producers, including cuttings, borings, shavings, and turnings.

- Government issues and remedies
  a. Taking advantage of higher quality of copper import policy's in other countries, India can allow imports of secondary Cu materials with lower metallic content. To attract more copper resources, the Indian government cut import duties on copper scrap by half in February 2021, to 2.5 % from 5.0 %.

  b. Most of the companies in India have not been registered due to environmental concerns and tax liabilities. So, Government of India needed to develop a strategy for collection of end-of-life copper and promote recycling industries in the country for efficient recycling and recovery of copper.

  c. Lack of an established collection system copper industry in India, which utilizes diverse types of old copper scrap, is highly unorganized and is dominated by small and medium enterprises in handicrafts, utensils, art ware etc. Thus, organised sector for collection needs to come in place.

- ***Role of the stakeholders:***
  Future growth in the copper recycling industry boasts the potential to enable decarbonization, although scrap will need to be part of a much broader low-carbon energy transition drive. The copper scrap sector faces many challenges, some of which can be addressed by increased investment in capital equipment and technology. An active role by governments will be crucial to the copper sector's impact on decarbonization, through promotion of green policies, incentives to accelerate investment and fostering conditions for wider circularity. Restrictions on global trade of copper scrap, triggered by new trade guidelines, could push domestic industries to invest in the copper secondary market while also creating new recycling hubs. In contrast with the steel industry, however, where a comparatively greater abundance of scrap supply could accelerate decarbonization, the constraints on copper scrap supply are expected to have a more muted impact, thus keeping primary copper ore as the major player in the copper market for the near future.

7.6 Chapter Contributors

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