Innovation Insight Report

India: Advanced Materials

June 2023

This report was written in 2022 and the information contained within this report remains correct at the time of production.

Contents

Executive Summary

The UK and India are natural partners in many areas of business, education, research, and innovation. Both countries have been working towards deepening ties in the areas of cross-country trade and innovation, research and development collaborations, and co-innovation. Multiple stakeholders of the two countries across industry, academia, and research bodies have developed strong relationships based on complementary strengths and common interests.

Advanced manufacturing is a key sector in India-UK bilateral trade and for future collaborations in technologies, research, and innovation. There is a growing potential for India and the UK to work closely in the advanced materials sector to co-develop new materials solutions that can benefit both economies and address the growing needs of energy efficiency, sustainability, circular economy, energy security, and supply chain reliability.

The report aims to identify areas where collaborative working can accelerate technology towards commercialisation through new research and innovation initiatives. Both countries have successfully worked on a number of projects in the advance materials sector and a useful way forward will be to build on these successes and explore new opportunities in a range of sub-sectors in the advanced materials sector.

It is hoped that this report will stimulate the interest of both the Indian and the UK advanced materials industries to explore areas of collaborations, and lead to initiation of new programmes for closer engagement on specific opportunities, supported by key stakeholders.

Glossary

2DMs	Two-dimensional materials
AB-PMJAY	Ayushman Bharat Pradhan Mantri Jan Arogya Yojana
ACC	Advanced Chemistry Cells
AIR	Academic Innovation Research
AMR	Automatic meter reading
AMTZ	Andhra Pradesh Medtech Zone
ARCI	International Advanced Research Centre for Powder Metallurgy & New Materials
AT	Asymmetric transmission
BHU	Benaras Hindu University
BIPP	Biotechnology Industry Partnership Programme
BIRAC	Biotechnology Industry Research Assistance Council
CeNS	Centre for Nano and Soft Matter Science
CeNSE	Centre for Nano Science and Engineering
CFRP	Carbon Fibre Reinforced Polymer
CGCRI	Central Glass and Ceramic Research Institute
CII	Confederation of Indian Industry
CIPET	Central Institute of Petrochemicals Engineering & Technology
C-MET	Centre for Materials for Electronics Technology
CMM	Chiral metamaterial
CMOS	Complementary metal-oxide-semiconductor
COP 26	The 26th United Nations Climate Change conference, held in Glasgow, Scotland, United Kingdom, from 31 October to 13 November 2021
CRNTS	Centre for Research in Nanotechnology & Science
CSIR	Council of Scientific and Industrial Research
CSIR-CECRI	Council of Scientific and Industrial Research-Central Electrochemical Research Institute
CSIR-NAL	Council of Scientific and Industrial Research-National Aerospace Laboratories
CSIR-NML	Council of Scientific and Industrial Research-National Metallurgical Laboratory
CVD	Chemical vapour deposition
DBT	Department of Biotechnology
DCPC	Department of Chemicals and Petrochemicals
DIT	Department for International Trade
DMSRDE	Defence Materials Stores and Research & Development Establishment
DRDO	Defence Research and Development Organisation
DSIR	Dholera Special Investment Region

DST	Department for Science and Technology
ETP	Enhanced Trade Partnership
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles in India
FDI	Foreign Direct Investment
FMCG	Fast Moving Consumer Goods
FSSAI	The Food Safety and Standards Authority of India
FTA	Free Trade Agreement
GERD	Gross Expenditure on R&D
GFRP	Glass Fibre Reinforced Polymer
GII	Global Innovation Index
GLAD	Glancing Angle Deposition
GoI	Government of India
GWU	Guided wave ultrasound
HA	Hydroxyapatite
HDPE	High Density Polyethylene
HSTPL	Hyper Stealth Technologies Pvt Ltd
IC IMPACT	India-Canada Centre for Innovative Multidisciplinary Partnerships to Accelerate Community Transformation and Sustainability
IISC	Indian Institute of Science
IISER	Indian Institutes of Science Education and Research
IIT	Indian Institute of Technology
IMPRINT	Impacting Research Innovation and Technology
JNCASR	Jawaharlal Nehru Centre for Advanced Scientific Research
LaNOM	Laboratory for Nanoscale Optics and Metamaterials
LDH	Layered double hydroxides
LSRB	Life Science Research Board
MECSP	Material for Energy Conservation and Storage Platform
MES	Materials for Energy Storage
MHIPE	Ministry of Heavy Industries and Public Enterprises
MHRD	Advanced Materials and Healthcare
MML	Microwave Metamaterial Laboratory
MSME	Micro, Small, and Medium Enterprises
NAL	National Aerospace Laboratories
NATAG	Nano Applications and Technology Advisory Group
NCL	India's National Chemical Laboratory
NGO	Non-Government Organisation
NHS	National Health Stack
NMC	Nano Mission Council

NSAG	Nano Science Advisory Group
NTHU	National Tsing Hua University
NUS	National University of Singapore
PLI	Production-linked Incentive
PMSTIAC	Prime Minister’s Science, Technology and Innovation Council
PSPD	Paperboards and Specialty Papers Division
PV	Photovoltaic
R&D	Research and Development
SBIRI	Small Business Innovation Research Initiative
SERB	Science and Engineering Research Board
SMC	Suzuki Motor Corporation
SPARC	Scheme for Promotion of Academic and Research Collaboration
STI	Science, Technology, and Innovation
SUPs	Single-use plastics
TACO	Tata AutoComp Systems Limited
TAML	Tata Advanced Materials Limited
TCS	Tata Consultancy Services
TIFR	Tata Institute of Fundamental Research
TRL	Technology Readiness Level
TSAMRC	Tata Steel Advanced Materials Research Centre
TSL	Tata Steel Limited
TSLNMB	Tata Steel New Materials Business
UKIERI	UK India Education and Research Initiative
UKRI	UK Research & Innovation
WRAP	West and Resources Action Programme
WTO	World Trade Organisation

India and the UK: A Growing Relationship

India and the UK share a long relationship in language, people, science, innovation, business, and technology. The two countries work closely on many multilateral forums, including the United Nations, the World Trade Organisation (WTO), and the Commonwealth.

The Enhanced Trade Partnership (ETP), launched by the Prime Ministers of India and the UK in May 2021, aims to double the bilateral trade by 2030, currently at about £23 billion, and address various trade barriers to unlock the full trade potential between the two countries. The Roadmap 2030 will pave the way for a deeper and stronger engagement between India and the UK over the next ten years in the key areas of people-to-people contact, trade and economy, defence and security, climate action, and health. The ETP declared India and the UK's shared intent to begin a comprehensive Free Trade Agreement (FTA). India and the UK launched the negotiations on the proposed FTA in January 2022. The UK's Department for International Trade (DIT) is leading in drawing up the UK's strategic approach for this FTA[1].

The Prime Minister of the United Kingdom, Rt Hon Boris Johnson MP, visited India at the invitation of the Prime Minister of India, Shri Narendra Modi, in April 2022. During this visit, the two Prime Ministers welcomed the intensification of bilateral engagements since the Virtual Summit in May 2021 and the positive momentum in cooperation across the full spectrum of bilateral relations.[2]

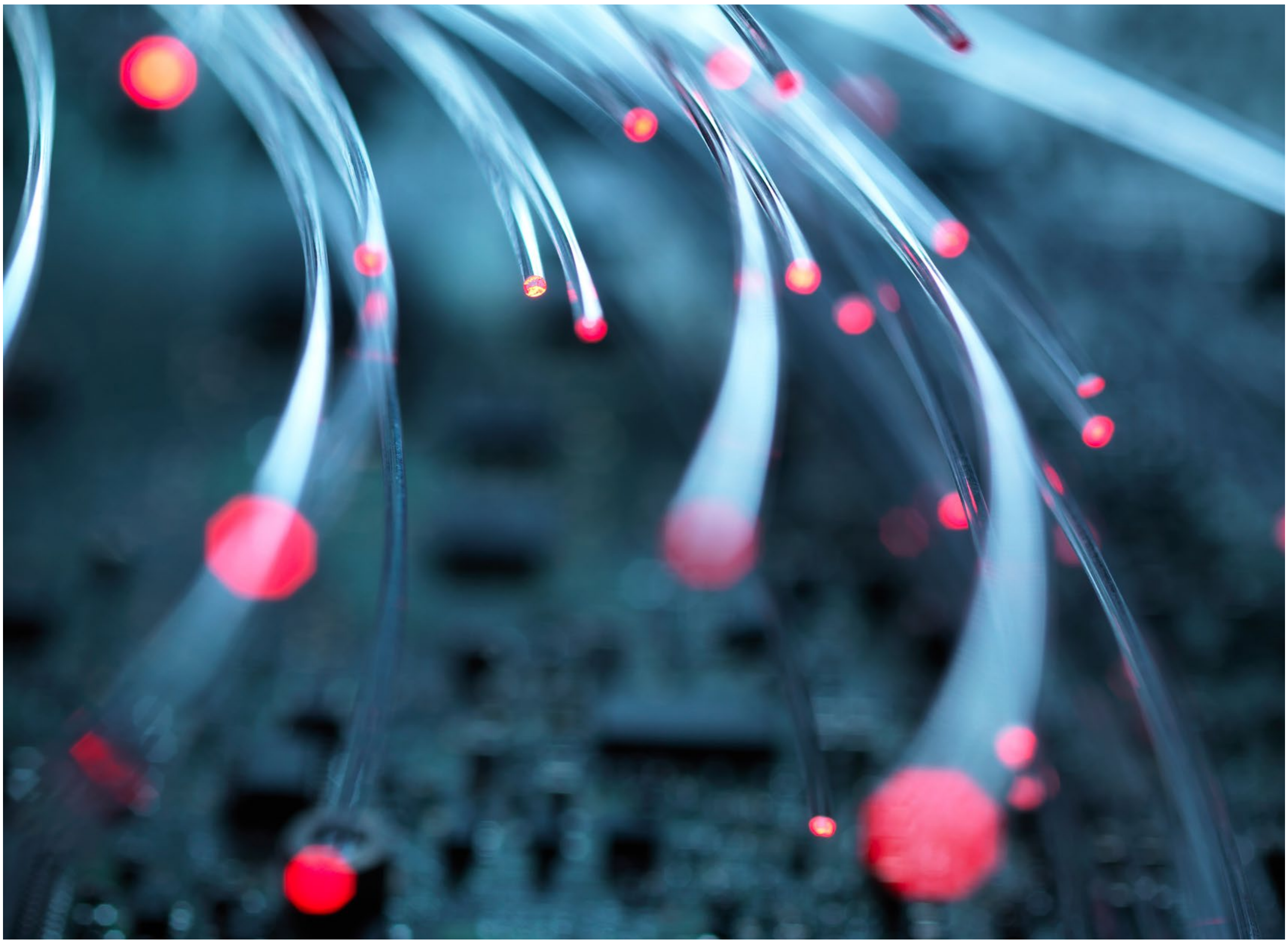
Aside from many sector-specific initiatives led by DIT, various other programmes such as the UK-India Education and Research Initiative (UKIERI), the UK-India Tech Partnership, the Global Entrepreneurship Programme, Tech Rocketship Awards, the UK-India FinTech Awards, Prosperity Fund, Newton Fund, and the initiatives of UK Research & Innovation (UKRI) are creating many partnerships between the two countries in the areas of education, science, research, innovation, and business. Moreover, since its launch in India in 1983, the UK's Chevening Scholarships programme has helped more than 3,000 professionals from India pursue a range of courses in the UK, and these "living bridges" are further strengthening the links between the two countries in science, innovation, media, and business.

Growing opportunities in India are attracting both exports and investment from the UK. The UK is the sixth-largest investor in India. About 572 UK companies are present in India with a combined turnover of around INR 3,390 billion (£33.9 billion), employing 416,121 people directly in 2019-20.[3] India was the UK's fifteenth largest trading partner in the four quarters to the end of Q2 2021 accounting for 1.6 per cent of total UK trade. In 2019, the outward stock of foreign direct investment (FDI) from the UK in India was £15.3 billion, accounting for one per cent of the total UK outward FDI stock. In 2019, the inward stock of FDI from India was £9.5 billion, accounting for 0.6 per cent of the total UK inward FDI stock. Total UK exports to India amounted to £7.3 billion in the four quarters to the end of Q2 2021 (a decrease of eight per cent compared to the four quarters to the end of Q2 2020).[4] The drop in bilateral trade in the last 18 months was largely due to the disruption caused by the COVID-19 pandemic. It is hoped that the volume of bilateral trade and investment will witness moderate growth in the coming months with the relaxation of COVID-19 restrictions.

India's Innovation Ecosystem

India announced the years 2010-2020 as the Decade of Innovation. Kick-started with the setting up of the National Innovation Foundation in 2000, the decade saw a series of policy initiatives. The 4th Science, Technology, and Innovation (STI) Policy was launched in 2013, and the next edition, the 5th STI Policy 2020[5] is now being introduced.

In between, the Government of India (GoI) introduced Make in India, Skill India and Start-up India – three flagship initiatives respectively for developing a strong manufacturing sector, supporting Indian youths with vocational and market-relevant training programmes, and creating a robust start-up ecosystem in India. India's Gross Expenditure on R&D (GERD) increased by more than three times in the last decade and India's per capita R&D expenditure at purchasing power parity (PPP) doubled in the last ten years[6]. India moved to the 40th rank in the Global Innovation Index (GII) 2022, published by the World Intellectual Property Organization.[7] When compared to India's 81st ranking in 2015, this is substantial progress.



India's Research and Innovation Strengths

- India went from being ranked 81st in the Global Innovation Index in 2015, to 40th in 2022.
- India moved up 79 places in the last six editions in the World Bank's Global Ranking in Ease of Doing Business (from 142nd to 63rd).
- India's GERD increased by more than three times in the last decade. India's per capita R&D expenditure at PPP doubled in the last ten years.
- India holds the third position globally in the number of scientific and technical publications in materials science and related fields.
- The last two years saw close to 1,700 patents filed in India in the materials sector.
- India has the third largest start-up ecosystem in the world and is home to 88 unicorns with a total value of £226 billion. Start-ups such as Log9 Materials and Fabheads have successfully raised VC funding. The advanced materials sector also receives growing support from large companies such as Tata Steel's MaterialNext programme.
- More than 50 per cent of the world's largest R&D spenders have a research and innovation presence in India.
- Growing international interests: Deakin University, Australia, has set up a Centre of Excellence with IIT Madras and IIT Hyderabad on Advanced Materials and Manufacturing. Fraunhofer Institute has long-standing relationships with several Indian institutes and companies.

India's policy landscape has witnessed several changes in the past decade. GoI established the National Institution for Transforming India, also called the NITI Aayog, as the premier policy think-tank to provide both directional and policy inputs, and technical advice to GoI and the Indian state governments. India's research and innovation (R&I) ecosystem has been supported by many government initiatives in recent years. Notable initiatives are mentioned below.

- **Uchhatar Avishkar Yojana (UAY)**: Run by GoI's Ministry of Human Resource Development (MHRD), this programme supports industry-sponsored, outcome-oriented research projects.
- **Atal Innovation Mission (AIM)**: This initiative of NITI Aayog and GoI's flagship programme aims to promote innovation and entrepreneurship in India.
- **Impacting Research Innovation and Technology (IMPRINT)**: This is a pan-IIT (Indian Institutes of Technology) and IISC (Indian Institute of Science) initiative to jointly work on accelerating innovation and research.
- **Scheme for Promotion of Academic and Research Collaboration (SPARC)**: Launched in 2018, by the Indian Ministry of Education, SPARC aims to improve the research ecosystem at higher education institutions by facilitating academic and research collaborations between Indian institutions and the best institutions globally.

In 2019, the Indian Prime Minister's Science, Technology, and Innovation Council (PMSTIAC) launched nine national priority missions to catalyse collaborations across scientific ministries, research institutions and industry partners and foster effective public-private links for driving research and innovation. The missions address major scientific challenges to ensure India's sustainable development – natural language translation, quantum frontier, artificial intelligence, national biodiversity, electric vehicles, bioscience for human health, waste to wealth and deep ocean exploration.[8]

Aside from the above initiatives, various GoI ministries and departments support sector-specific and cross-sectoral R&I programmes. GoI's Department for Science and Technology (DST) supports a range of research projects, many in the advanced manufacturing and materials sector, in several research institutions, academic bodies, and various laboratories of the Council of Scientific and Industrial Research (CSIR). Aside from DST, the Ministry of Electronics and Information Technology (MeitY) and the Department of Biotechnology (DBT) are supporting several projects in the areas of electron materials, electrification, and biomaterials. During the financial years 2020-21 and 2021-22, GoI announced production-linked-incentive (PLI) schemes in ten industrial sectors.[9] These PLI schemes aim to make Indian manufacturers globally competitive, attract investment in the areas of core competency and cutting-edge technology; ensure efficiencies; create economies of scale; enhance exports and make India an integral part of the global supply chain. The PLI schemes for the automotive sector, advanced chemical cell storage batteries, and large-scale electronics manufacturing schemes for the promotion of manufacturing of electronic components and semiconductors are of particular relevance to the advanced materials sector as these are driving growing investments not only in new production facilities but also in several research initiatives.

India needs to undertake strategic efforts to strengthen the innovation ecosystem to boost its economy and become a top global player in research, technologies, and innovation. Some of the key constraints and bottlenecks that need the attention of GoI policy makers, academia and the business sector are discussed below.

India needs a sustained increase in R&D expenditure and aims to spend at least two per cent of GDP on R&D and innovation-related activities. GoI and various government agencies have always led the R&D spending, which now needs more robust participation by the business sector. Multiple agencies drive the policies on R&D, innovation, and entrepreneurship; some have intersecting and overlapping roles. This calls for a more coordinated approach and better coordination amongst these agencies and departments. Weak links between industry and academia in India due to the lack of a clear policy for strengthening these ties are a well-known and long-standing challenge.[10] A closer working relationship between industry and academia, seed funding assistance, and the development of industry-led R&D infrastructure will help resolve this long-standing issue.

Moreover, the benefits of new initiatives and policy interventions seem to be available to only a few states/cities or elite academic bodies such as the IITs and IISc. These need to trickle down to other deserving and broader geographies and academic/research bodies. As mentioned in NITI Aayog's India Innovation Index report 2020[11], there are some regional imbalances in terms of the location of research institutions which are somewhat concentrated in a few regions. It is felt that the public and private R&D bodies and supporting ecosystems should have more presence in the North-Eastern and the Central States of India. It is hoped that India will be able to address these challenges with necessary policy interventions, benchmarking international best practices, stronger participation of the private sector, and international collaborations. The UK can play a key role through cooperation and collaborations with GoI, R&I bodies, and leading private sector players in making the R&I ecosystem more robust.

Advanced Materials Sector in India

The Indian manufacturing sector is expanding fast, contributing 16-17 per cent to India's national Gross Domestic Product (GDP). Aside from plans to have manufacturing facilities of global size and scale, leading Indian companies aspire to move up the technology value chain fast, and access to technology is often considered a key growth enabler.

Historically, the industry spent only a negligible fraction of its income on research and innovation. The Gross Expenditure on R&D has been hovering at about 0.7 per cent of GDP for a decade.[12] India's Economic Survey 2021 called for an increase in the private sector's investment in R&D. As discussed in this report, many key players in the advanced materials sector are planning large scale and cutting-edge research projects. Aside from in-house R&D efforts, Indian companies often look to collaborate with global technology leaders; having an overseas R&D presence; and investing in innovative technology companies and start-ups.

This report discusses the R&I ecosystem, policy initiatives and growth enablers, ongoing R&I and potential for future collaborations in various areas of the advanced materials sector, such as composites, graphene and 2D materials, nanomaterials, metamaterials, plastics and sustainable packaging, and materials for electrification and energy storage for applications in a range of sectors including advanced manufacturing, automotive, aerospace, defence, and healthcare industries.

Composites

India's composite industry, valued at INR 110 billion (£1.1 billion) and growing at 12-15 per cent per year, comprises manufacturers of fibres, resins and chemicals, and composites components.

India's Composite Industry: Key Facts

Main segments: Glass Fibre Reinforced Polymer (GFRP) composites (75 per cent) and Carbon Fibre Reinforced Polymer (CFRP) composites.

End-use and application areas: Mainly commoditised applications (65 per cent) (for example, GFRP pressure vessels, chemical tanks and equipment, gratings, pultruded sections, pipes, components for automotive and railways, cooling towers and various process industries) and high-end applications (35 per cent) (for example CFRP components for aerospace and defence sectors, and wind energy).

Key manufacturing technologies: Filament winding, pultrusion, and hand lay-up.

The early years of the composites industry saw the domination of small-scale organisations working independently. However, recent years have witnessed the entry of large companies, including the Tata Group and Reliance Industries, and a few more large players, such as the Aditya Birla Group, Arvind Group and Lakshmi Metal Works. Some start-ups, too, are looking at developing new composite solutions and manufacturing technologies. For example, Fabheads, incubated at the Indian Institute of Technology Madras, has developed continuous fibre 3D printers for the composite industry.

India's Composite Industry: Leading Domestic Players

Tata Group
Three group companies are engaged in the composites business:

- Tata Steel New Materials Business (TSLNMB): GFRP components for process industries, infrastructure, and railways. Business activities include medical materials and technical ceramics.
- Tata Advanced Materials Limited (TAML): CFRP components for the aerospace and defence sectors. TAML has been brought under Tata Aerospace and Defence to consolidate all Tata Group businesses in the aerospace and defence sectors.
- Tata Auto Components (TACO): Composite components for the automotive sector.

Reliance Industries (RIL)
GFRP components for a range of sectors. RIL announced their plan to set up a carbon fibre manufacturing unit in India for aerospace and defence, and specialised industrial applications.[13]

Aditya Birla Group
Epoxy resins and technical textiles. They have developed recyclable epoxy resins and recycling solutions for wind blades.

National Aerospace Laboratories (NAL) and Hindustan Aeronautics Limited (HAL)
Both are primarily engaged in the manufacture of CFRP components for the aerospace sector. NAL also has carbon fibre and prepreg manufacturing facilities.

Policy Landscape

The Indian composites industry, growing at 12-15 per cent per year, is poised for a major expansion as the end-user industries seek lightweight and energy-efficient solutions. Large investments in the electric vehicles (EV) sector, boosted by several GoI initiatives and incentives from both central and state governments for demand creation for EVs (details discussed in this report under the section on Materials for Electrification and Energy Storage), growing spending on creating domestic manufacturing capabilities under the Make in India initiatives, and large urban and transport infrastructure (including expansion and new projects of Metro rail networks) are creating demand for advanced composites solutions. Moreover, policies and initiatives in the areas of waste management, sustainability, and the circular economy are creating applications area for composite products in the renewable and clean energy sectors, such as solar and wind power, and green hydrogen industries, and demand for sustainable and affordable solutions for disposable and recycling and re-use of composite products.

Research and Innovation Ecosystem

Large Indian players in the composites industry are investing in R&D and new product development. For example, Tata Steel New Materials Business (TSLNMB) developed India's first composite-based foot overbridge in 2019. Following this initial success, TSLNMB delivered a fully functional bridge for a golf course in 2020.[14] TSLNMB also developed India's first fully composite-made quarantine cabins for a COVID-19 hospital in Kerala, India.[15] The National Aerospace Laboratory has set up the Advanced Composites Division in Bengaluru.[16] This is a Centre of Excellence for composite structures in India and has developed innovative design and manufacturing approaches for composites structures for the aerospace industry. Aditya Birla Advanced Materials have developed recyclable composite wind blades for Siemens and Gamesa. Leading global glass fibre manufacturers, such as Owens Corning and Jushi, have a presence, and work with Indian players on new technologies and product ranges.

Aside from running R&D programmes with several Indian institutes of technology and other academic research bodies, Indian manufacturers are creating relationships with global industry players, academia, and research bodies. For example, Tata Steel has been working with the UK's National Composites Centre in Bristol.[17]

Examples of current innovations

Tata Steel Limited	Aditya Biria Group
• COVID-19 quarantine units, made of GFRP for a COVID hosital in Kerala, India in 2020. • Developed the first composites foot over bridge in India in 2019, installed a fully functional GFRP bridge at a golf course in India.	• Developed recyclable wind blades for Siemens Gamesa in 2021 • Developed recyclable epoxy resins for Cobra International-production of water sports components. Won JEC award in 2020.

Potential Areas of Collaboration

Though India has adequate manufacturing facilities to cater to the domestic demand for commoditised composite products, it imports most of its requirement of high-strength glass fibres and almost the entire requirement of carbon fibres, including carbon-fibre-based prepregs. (Prepregs are composites having reinforced fibres, pre-impregnated with thermoplastic or thermoset resin without curing.)

As the composites industry expands, India is likely to move up the technology value chain fast. The product mix, too, is expected to move from commoditised products to products with high-end applications in aerospace, automotive, motorsports, defence, sports, marine and wind energy. As summarised below, the growth trajectory of India's composites industry and technology strategies are creating a range of collaboration opportunities.

Key Opportunities for Future Collaboration

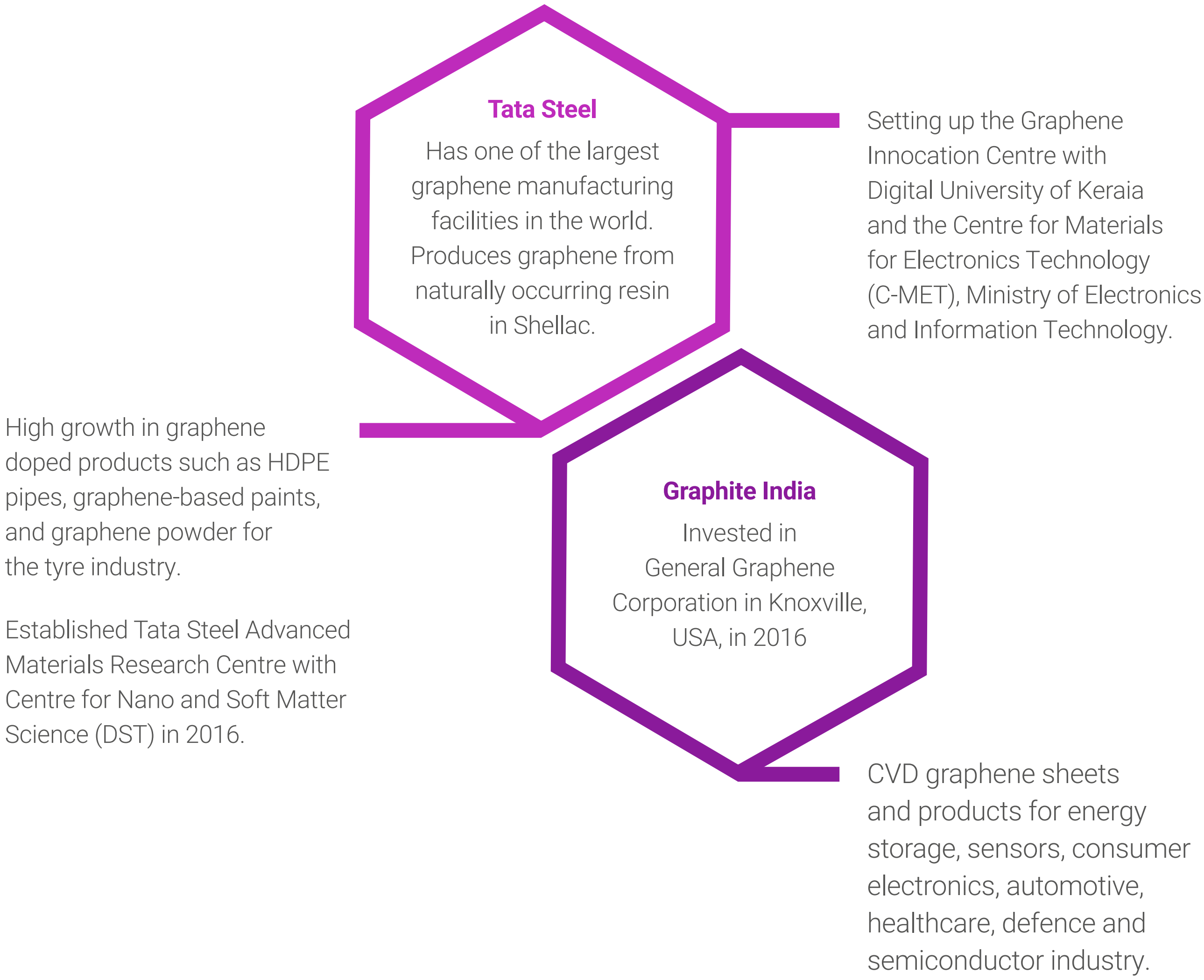
- Fibres: Technologies for the manufacture of carbon and high-grade glass fibres.
- New product and applications development: Composite products (such as rebars and products with unique geometries) for use in the construction sector. Products for marine, hydrogen (such as Type 3 and Type 4 cylinders), EV, energy storage, oil and gas, and renewables sectors.
- Recycling and reusing of carbon fibres from rejected prepregs and components, and sustainable and economical solutions for the recycling of end-of-life composites products.

Graphene and Two-Dimensional Materials

Graphene

Tata Steel and Graphite India are the two leading players in the graphene sector. While Tata Steel has set up its own graphene manufacturing facility in India, Graphite India entered the graphene business by investing in General Graphene Corporation, a company based in Knoxville, US.

Tata Steel is India's largest producer of graphene. Their R&D division invented a process to produce graphene from a naturally occurring resin in Shellac (a natural resin secreted by female lac [Laccifer lacca] insects). Over the years, Tata Steel has developed several graphene-based products, including corrosion-resistant graphene paint, graphene powder for tyre manufacturers, and graphene-doped HDPE pipes. In December 2020, Tata Steel commissioned a 100-tonne-per-annum integrated graphene manufacturing plant near Jamshedpur. This is one of the largest single-unit graphene production centres in the world.[18]



Kolkata-based Graphite India Limited, one of India's largest producers of graphite electrodes, acquired a 46 per cent stake in General Graphene Corporation at USD 18,59 million in 2016.[19] General Graphene aims to establish mass production of high-quality, low-cost chemical vapour deposited (CVD) graphene sheets and is looking at application development in the areas of energy storage, consumer electronics, sensor, semiconductor, automotive, healthcare, and defence sectors.[20]

Policy Landscape

Indian graphene producers are producing graphene-coated and doped solutions for the tyre and process industries, and graphene is also used in corrosion-resistant paints and as an additive to improve the performance of HDPE pipes. There is a growing interest in graphene producers to cater to the electronics sector. The growth of digital manufacturing and the electronics industries creates an interesting mix of opportunities for graphene and other two-dimensional materials (2DMs). Large Indian groups such as the Tata Group and Reliance Industries have recently announced their plans for the electronics and semiconductor industry, and GoI's PLI scheme for the large electronic industries[21], introduced by MeitY, is expected to be a significant growth enabler for graphene/2DM-based products for the electronics sector.

Research and Innovation Ecosystem

There are ongoing research projects undertaken by several academic bodies, including various Indian institutes of technology (such as the Graphene Centre at the Indian Institute of Technology, Bombay, and the Centre for 2D Materials Research and Innovation at the Indian Institute of Technology, Madras) and the Centre for Nano Science and Engineering (CeNSE) in the Indian Institute of Science. Many run industry-sponsored research and work with SMEs and start-ups. For example, Tata Steel has been working with the Centre for Nano and Soft Matter Science (CeNS), an autonomous institute under the DST, on developing new graphene-based solutions and nanotechnology. Tata Steel set up the Tata Steel Advanced Materials Research Centre (TSAMRC) at CeNS in October 2016.[22] Tata Steel has worked in the past with the University of Warwick on a range of surface coatings, including graphene at their research centre in the university's science park.[23] Tata Steel is now supporting the upcoming Graphene Innovation Centre in India.

Graphene Innovation Centre

Tata Steel, in a joint venture with the Digital University of Kerala and the Centre for Materials for Electronics Technology (C-MET), a unit of MeitY, is setting up India's first Graphene Innovation Centre in Thrissur, Kerala, at INR 864 million (£8.64 million).[24] The centre will help students, researchers, and start-ups undertake R&D projects on graphene.

Potential Areas of Collaboration

Indian companies such as Tata Steel and new entrants such as Log9 Materials and Tirupati Graphene in the graphene sector are primarily looking to develop applications in new areas and related synthesis and scaling-up opportunities.

Indian industry is looking to innovate the use of graphene in the following ways:

- Conductive inks.
- Electronics including flexible photovoltaics.
- Textiles.
- Construction sector.
- Energy storage.

Other Two-Dimensional Materials

In the areas of other two-dimensional materials (2DMs), most of the research and innovation projects in India are at a low (3-5) Technology Readiness Level (TRL). While research is led mainly by academic institutions, with support from various GoI departments, there is growing interest from the private sector. Most of the ongoing research on 2DMs focuses on the development of electronics and optoelectronics applications of these materials using their exotic optical and electronic properties and unique mechanical characteristics from their atomically thin structures. Some 2DMs can help create heterogeneous platforms together with conventional silicon-based CMOS and are excellent candidates for next-generation electronic devices.

Case Studies:
India-UK Collaboration in Two-Dimensional Materials

- India's National Chemical Laboratory (NCL) and the UK's Centre for Process Innovations are looking to create a UK-India collaborative R&D programme with the participation of industry and other research partners to develop high-value products for sustainability, energy security, circular economy, and supply chain security. One of the initial focus areas is 2D nanomaterials.

- The UK India Education and Research Initiative runs projects under the Scheme for Promotion of Academic and Research Collaboration (SPARC). In recent years, some of the SPARC events focused on 2D and nanomaterials. One of the latest series of SPARC webinars, held on 10 March 2022, showcased the ongoing work on 2D and nanostructured phenomena, materials, and devices between India's National Chemical Laboratory; and the Centre for Processed Innovations, UK; the UK's National Graphene Institute, The University of Manchester; and the Department of Materials Science and Metallurgy, University of Cambridge.[25]

Brief details of the key Indian academic and other research bodies working in the field of 2DMs such as hexagonal boron nitride (h-BN), metal di-chalcogenides and tri-chalcogenides, metal oxides and carbides, phosphorene, and MXenes are given below.

- **Centre for 2D Materials Research and Innovation, Indian Institute of Technology Madras:** CVD growth of materials and their heterostructures, development of low power electronic and optoelectronic devices from 2D materials, and high-quality electronics and optoelectronics from novel atomically thin quantum materials. Their national-level industry collaborator is Ants Innovations Pvt Ltd, and international collaborators include UNIST, South Korea; NTHU, Taiwan; University of Central Florida, US; University of Manchester, UK; Centre for Advanced 2D Materials, NUS Singapore; Ajou University, Republic of Korea; and Tel Aviv University, Israel.
- **Nanoscale Electro-Optic Devices and Superconductivity Lab, Indian Institute of Technology (IIT), Delhi:** Graphene-based spin and photovoltaics, 2D heterojunction electro-optics, low dimensional electron transport, two-dimensional molecular sieves, ultra-thin and stable MoS_2, graphene membranes for separation, energy, and environmental applications. Industry collaborators include Axiva Sichem Biotech and Lupin Ltd.
- **Centre for Nano Science and Engineering (CeNSE), Indian Institute of Science, Bangalore:** Indian Institute of Science and KAS Tech, US, have together developed a commercially available graphene-producing system. CeNSE works on a whole library of 2DMs, such as graphene, which is a conductor, MoS_2 and WS_{e2} which are both semiconductors; and boron nitride, an insulator. Industry collaborators include Bharat Electronics, AM Research, ASM technologies, Rakon, Centum, L&T Technology Services, Philips, and Shell India.
- **Nanostructures Engineering and Modelling Laboratory, Indian Institute of Technology, Bombay:** Research interests include V_2O_5, MOS_2, stanene, monolayers of transition metal chalcogenides, MXene and phosphorene, graphene, polymer composite; and Ni/Mn/other layered double hydroxides (LDH) materials for supercapacitor applications.
- **Indian Institute of Technology, Kharagpur:** Graphene, MoS_2, WS_2 and hybrid 2D nanostructures semiconductor nanostructures and 2DMs for advanced energy, environment and biosensing applications, graphene-based foam, hexagonal boron nitride (hBN), MoS_2, dichalcogenides, and ReS_2. Their collaborators include Rice University, The University of Texas, Oak Ridge National Laboratory, the US Air Force Research Laboratory, and the University of Delaware.

Emerging Private Sector Interests in 2DMs

Aside from academia and GoI-supported research bodies, some companies have started taking an interest in 2DMs and their innovative applications. They include:

- Adnano Technologies: Various forms of graphene and multiwalled carbon nanotubes.
- Avanasa & Services: Carbon nanotubes, graphene, and various nanoparticles.
- BT Corporation. Bulk production of graphene, application development and contract research.
- Carborundum Universal: Graphene powder.
- Aritech Chemazone. CVD graphene, various nanoparticles and quantum dots, and speciality chemicals such as MoS_2.
- SPEL Technologies: Graphene-based supercapacitors, reduced graphene oxide electrode materials, and Mxene.

Sustainable Plastics and Packaging

India has a large plastics industry worth about USD 36 billion (£30 billion), growing at a rate of 6.6 per cent CAGR. One of the plastic industry's major strengths is the domestic availability of raw materials such as polypropylene, high-density polyethylene, low-density polyethylene, and PVC.[26] Driven by several policy interventions by GoI and initiatives of leading producers and end-users, there is a growing demand for sustainable plastics and alternative packaging materials.

Policy Landscape

Several GoI policies and industry initiatives are expected to pave the way for the growth of India's sustainable food packaging sector. Details of some of the main policy initiatives are summarised below.

Key Policy Initiatives

- GoI initially proposed a complete ban on using all forms of single-use plastics (SUPs) in two phases, commencing 1 January 2020. The Plastic Waste Management Amendment Rules, 2021, announced in August 2021, stated that 20 identified SUPs would be phased out by the end of 2022, and it is expected that this ban would come into force from July 2022.
- The Report on Single-Use Plastics,[27] produced by an expert committee and commissioned by the Department of Chemicals and Petrochemicals (DCPC), has categorised plastic products based on their environmental impact and utility. The plastics found to have the lowest utility and highest environmental impact are recommended for phase-out.
- The Food Safety and Standards Authority of India (FSSAI) is pushing for a plastic-free food sector and is taking several steps towards implementing green and sustainable technologies for food distribution.[28,29]
- In January 2022, FSSAI issued a notice specifying the authorisation mechanism for recycled plastics manufacturers as per the draft Food Safety and Standards (Packaging) Regulations, 2022, for permitting the use of recycled plastics as food contact materials.[30]

Key policy issues and growth enablers

Proposed ban on single-use plastics

The proposed ban on single-use plastics by the Governement of India is expected to be come into force from July 2022

FSSAI initiative

FSSAI is pushing for green and sustainable use of plastics in the food sector

FSSAI: The Food Safety and Standards Authority of India

Indian Plastic Pact (Supported by UKRI)

Launched in September in 2021, this is a collaboration between CII and WWF, supported by multiple stakeholders and UK Research & Innovation with a commitment of £250,000

Sustainable packaging measure by user industries

Led by leading FMCG companies and e-commerce companies

Key Policy and Other Initiatives

Industry Initiatives

In line with the GoI policies, the end-user industries such as food and beverage, food processing, e-commerce, and fast moving consumer goods (FMCG) companies; various chambers of commerce, and the leading industry body, the Confederation of Indian Industry (CII), have initiated several measures for moving towards a circular plastics economy and growing use of sustainable plastics and packaging.

India Plastics Pact

Launched on 3 September 2021, the India Plastics Pact is a collaboration between India's leading industry body, the CII and WWF, supported by multiple stakeholders to move towards time-bound and target-based commitments to migrate from the current linear plastics system into a circular plastics economy.

The pact is supported by UKRI and the West and Resources Action Programme (WRAP), UK, and endorsed by the British High Commission in India. In 2020, UKRI committed £250,000 of funding to enable WRAP to establish the pact.

India is the first Asian country to develop a plastic pact that seeks to transform the entire plastics value chain through a public-private collaboration with ambitious measurable targets by 2030. The stakeholders include as many as 27 businesses and supporting organisations such as major FMCG brands, various manufacturers including the Tata Group, consumer products and e-commerce companies such as Amazon, Hindustan Unilever, Coca-Cola India, Godrej, Marico and ITC.[31,32,33,34,35]

Many large FMCG companies have announced plans to move fully to sustainable and recyclable packaging by 2025.[36,37] A few examples of some encouraging measures introduced by leading companies are shown overleaf.

Examples: Sustainable Packaging Measure by Leading Private Sector Players

- **Pepsi's** 2025 packaging sustainability agenda includes designing packaging that is 100 per cent recyclable, compostable or biodegradable, ensuring at least 25 per cent of recycled content in their packaging; collaborating with suppliers to raise consumer awareness, advocating improved recycling infrastructure and regulatory reform and reducing the use of virgin plastic by 35 per cent across their beverage portfolio by the year 2025.[38]
- E-commerce giant **Flipkart** is working towards reducing the need for an outer layer of packaging and has eliminated all SUP packaging. Flipkart Group, which includes online marketplace Flipkart and Myntra, has partnered with not-for-profit Canopy to source sustainable packaging, in a bid to extend their commitment towards sustainability.[39]
- **Mondelez** India has announced a grant to Hasiru Dala, an NGO that will recycle multi-layered plastic (MLP), a prominent packaging material used by the company. They have also claimed that over 97 per cent of its packaging is designed to be recyclable, and their recycling initiative will turn about 600 tonnes of MLP waste into boards that can be used to make furniture and construction material.[40,41]
- **Tata Consumer Products** are implementing recyclable packaging for Tata Salt and Tata Tea brands to eliminate the use of multi-laminate packaging. They are also maximising the reuse of secondary packaging, resulting in efficient use of resources.[42]
- **Marico**, a leading FMCG company in the health, beauty, and wellness space, has joined a sustainable packaging partnership led by Dow Chemicals and Lucro Plastecycle. Under this initiative, Dow Chemicals will use its team of packaging experts, material scientists, recycling equipment, blown film manufacturing and testing capabilities at Pack Studios Shanghai and Mumbai to help Lucro develop recycled film for various applications.[43]

Research and Innovation Ecosystem

On the supply side, there is an attempt by several companies to introduce biopolymers and biodegradable and compostable plastic. Some leading companies in this area are Eco365, Aquent Advanced Materials Technologies and SKYi Innovations. There is a growing interest from companies to develop biodegradable and compostable plastic packaging solutions. Several companies are looking at developing bio-degradable plastics using polylactic acid.

GoI's Central Institute of Petrochemicals Engineering & Technology (CIPET) is the certifying body for compostable plastics and has plastic testing facilities at several centres throughout India. Though biodegradable and compostable plastic could be a viable and sustainable alternative to conventional plastics, scaling up plastic composting facilities is challenging. India has only very limited industry-scale plastic composting facilities.

There are several initiatives to encourage start-ups to come forward with their innovations in sustainable plastics and packaging. ITC Paperboards and Specialty Papers Division (PSPD), in collaboration with Invest India, has launched the ITC Sustainability Innovation Challenge for start-ups with innovative ideas on sustainable packaging and smart waste management solutions.[44] To encourage innovation in the development of alternatives to identified SUP items and digital solutions to plastic waste management, the India Plastic Challenge – Hackathon 2021, has been organised for students of higher education institutions and start-ups recognised under the Start-up India initiative.[45]

Case Studies: Foreign Interest in Innovation in Sustainable Plastics Sector in India

- SKYi India has set up a joint venture company, SKYi FKuR Biopolymers Pvt Ltd, with FKur Kunststoff GmbH, a sustainable plastics manufacturer from Germany, to establish a sustainable and biodegradable plastics manufacturing facility near Chakan in Pune.
- Dow Chemicals is supporting a young India-based recycling company, Lucro PlasteCycle, to develop and produce polyethylene film solutions made from locally collected, difficult-to-recycle plastic scraps. Dow Chemicals will use its team of packaging experts, material scientists, recycling equipment, blown film manufacturing and testing capabilities at Pack Studios Shanghai and Mumbai to support Lucro in the development of recycled film.[46] Circulate Capital, the Singapore-based investment management company, has invested in Lucro from their Circulate Capital Ocean Fund, which is dedicated to investing in start-ups solving ocean plastic crises in South and Southeast Asia.[47]

CSIR-National Chemical Laboratory (CSIR-NCL), Pune and SKYi Innovations signed a know-how licensing agreement for the process for the synthesis of hyperbranched polymers in January 2022. Hyperbranched polymers have many applications, such as compatibilisers for polymer blends, rheological properties modifiers for polymer-based systems, and chain extenders. The synthesis process uses commercially available raw materials and generates the hyperbranched polymer in a single reaction step. It is an eco-friendly process as it is solvent-free and involves a metal-free catalyst.[48]

Potential Areas of Collaboration

- Research on developing more sustainable packaging materials from organic sources.
- Clean recycling of plastics, especially for food contact applications.
- Development of advanced biodegradable and compostable plastics, such as polylactic acid-based plastic and other next-generation sustainable plastics for packaging.
- An innovative model for rapid roll-out and scaling up of plastic composting infrastructure.

Metamaterials

Metamaterials are a new generation of emerging materials that can control and manipulate the flow of light and sound, and generate exceptional properties not found in naturally occurring materials. The scientific activity on metamaterials mainly focuses on their unique structures' exotic and unconventional electromagnetic properties rather than their composition. Metamaterials are used to develop technologies related to beam shapes (for use in collimators, lenses, and reflectors), polarisers (for use in discriminators and rotators), absorbers (for use in reducing scatter and energy harvesting), sensors (in antenna, diodes, and arrays), resonators, plasmonic devices, and noise-cancellation applications.

Policy Landscape

Most of India's ongoing research and innovation work in the areas of metamaterials, currently at a low (3-4) TRL level, is led and supported by several GoI bodies and initiatives such as the Scheme for Promotion of Academic and Research Collaboration (SPARC) of MHRD; CSIR, DST, and Defence Research and Development Organisation (DRDO) and various defence research organisations under the Ministry of Defence. In 2021, DST, under its Advanced Manufacturing Technologies Programme, called for R&D proposals aiming to achieve TRL 3-4 on a few advanced manufacturing and materials themes, including the manufacturing of nanomaterials, electronic grade materials, smart materials, and metamaterials.[49]

Research and Innovation Ecosystem

In the nascent and low-TRL research on metamaterials and plasmonics, India is working with many countries globally, such as the US, France, Switzerland, Russia, Singapore, and Japan. Below is an example of collaborative working between India and the UK.

Case Study: India–UK Collaborative Work in Metamaterials

In 2020, the Indian Institute of Technology, Guwahati, and Imperial College London, UK, developed a tailored "meta-grid" of nanoparticles that could make light-emitting diodes (LEDs) brighter, more energy-efficient and more durable. Meta-grid, or metamaterial grid, is a specifically patterned array (grid) of nanoparticles acting as metamaterials, capable of exhibiting extraordinary optical properties. Given the widespread use of LEDs, any increase in light output could significantly reduce energy needs on a large scale and, therefore, will contribute towards curbing global warming and climate change.[50]

Brief highlights of some of the ongoing research at various DRDO units and other institutes are presented below.

Case Studies: Ongoing Research Interests in Metamaterials

- **Defence Research and Development Organisation (DRDO):** DRDO is investigating different functional properties of various metamaterials for possible use in radar-absorbing material, digital altimeter indicators, parachutes, military textiles, helmets, dual-band flexible radar absorbers, and many other defence applications.[51,52]
- **Defence Materials Stores and Research & Development Establishment (DMSRDE), Kanpur:** They are working in the field of functional non-metallic materials, camouflage textiles, speciality clothing and shelter for services, fuels, and lubricants.[53,54]
- **Laboratory for Nanoscale Optics and Metamaterials (LaNOM), Department of Physics, Indian Institute of Technology (IIT), Ropar:** IIT Ropar is working across areas in the metamaterials field, such as photonic crystals, disordered structures, bio-inspired photonic structures, and two-dimensional photonic and atomic layered structures. LaNOM has collaborations with several overseas universities and research groups including TU Berlin, Germany; Moscow State University, Russia; and NUS, Singapore.[55]
- **Microwave Metamaterial Laboratory (MML), Indian Institute of Technology Kanpur:** MML is working on several application areas of metamaterials including microwave metamaterial-based absorbing technologies (multi-band and broadband), metamaterial inspired microwave antennas, and metamaterial-based polarisers, and control of resonances and optical properties of plasmonic-patch metamaterials. IIT Kanpur has been working with DRDO to develop material that can be used as uniforms for personnel and skirting or covering ground vehicles to avoid their detection by the enemy's advanced battlefield radars, motion-detecting ground sensors, and thermal imaging systems.[56]
- **Indian Institute of Technology Madras:** IIT Madras and the University of Nairobi, Kenya, are jointly investigating metamaterials to improve the detection of defects in large structures by guided wave ultrasound (GWU).[57]
- **Centre for Nano Science and Engineering (CeNSE), Indian Institute of Science, Bangalore:** CeNSE is investigating 3D plasmonic metamaterials, plasmonic interactions engineering in three dimensions to develop novel optical metamaterials, wafer-scale technology to fabricate porous 3D plasmonic metamaterial using GLAD (Glancing Angle Deposition), and integrated plasmonic to develop an arrangement of metal-dielectric layers in 3D. In addition, CeNSE is also fabricating metallic nanoparticles based on chiral metamaterials to utilise their strong chiro-optical response. These metamaterials are potential candidates for showing negative indices of refraction and may work as very efficient broadband polarisation devices.[58]
- **Indian Institute of Technology Bombay:** The research areas include metamaterial-based devices at microwave and millimetre wave frequencies, electromagnetic metamaterial, bandwidth-enhanced metamaterial absorbers for microwave applications, chiral metamaterial (CMM) for asymmetric broadband transmission of linearly polarised electromagnetic waves, designing optical lenses, absorbers and meta-surfaces through a variety of computational tools. Their current collaborators include Michigan State University, US.[59,60]

Aside from the above and other research being carried out in academia and research bodies, the private sector is increasingly interested in commercialising research outcomes. Here are two examples of private sector companies that have ventured to introduce metamaterial's commercial applications.

Hyper Stealth Technologies Pvt Ltd (HSTPL): Delhi-based HSTPL is a leading stealth solution provider against visual, UV, near-infrared, thermal and radar surveillance. They are also developing technologies for protection for 5G and MRI radiation, and protection of astronauts from gamma radiation in space. They recently won the Innovation for Defence Excellence (iDEX) start-up challenge award for Adaptive Stealth Coating Solutions.

Sahajanand Laser Technology: Driven by its R&D, the company offers acoustic, photonic, and stealth solutions to the aerospace and defence sector, and radar-absorbent materials, and works closely with DRDO, the Indian Space Research Agency, and several Indian institutes of technology.

Biomaterials

Policy Landscape: Government Policies and Initiatives

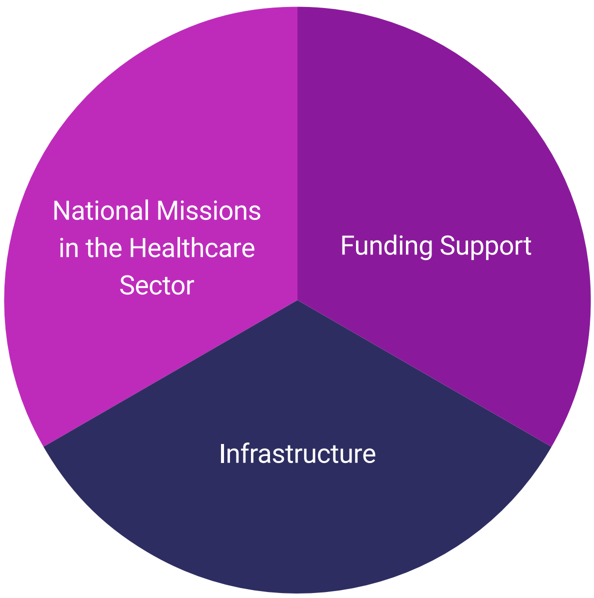
The potential economic and societal impact has driven significant research programmes on medical materials and implants globally over the last few decades. However, the outcome has yet to be significant in India, as more than 80 per cent of the implants used in hospitals are still imported. The Asia-Pacific market, especially India, is one of the fastest-growing medical implant markets in the world, and there are a growing number of research and innovations led by companies and research bodies. Several recent policy initiatives and growth enablers in the healthcare sector are helping bring in more private and foreign investment in medical materials, implants and medical devices. Some of the notable growth drivers are discussed below.

Key Policies and Other Growth Enablers

National Missions in the Healthcare Sector
- Ayushman Bharat Yojana.[61]
- National Health Stack.[62]

Funding Support
- Department of Science and Technology.[63]
- Department of Biotechnology.[64]
- Small Business Innovation Research Initiative.[65]
- Biotechnology Industry Research Assistance Council.[66]
- DRDO Life Science Research Board.[67]
- Indian Council of Medical Research.[68]
- PLI scheme for medical devices.[69]

Infrastructure
- Growing industrial clusters for medical devices such as Andhra Pradesh MedTech Zone.[70]



- **The Ayushman Bharat Yojana** is a national programme designed to establish 150,000 health and wellness centres for comprehensive primary healthcare offering preventative and promotive healthcare accessible to all. The Ayushman Bharat Pradhan Mantri Jan Arogya Yojana (AB-PMJAY) Start-Up Grand Challenge is a national initiative to stimulate the start-up community to generate solutions for empowering people to gain access to affordable healthcare.[71]
- The **National Health Stack** (NHS) is conceived as a digital infrastructure for implementing health initiatives, such as managing health data, coverage and claims, and enabling patients to access their health data and national health analytics. Through the NHS, NITI Aayog aims to initiate strategic policy actions to improve health security in what would be one of the largest healthcare programmes in the world. With the anticipated growth of the Indian market, there are ongoing initiatives to revamp the bioengineering and medical curricula in academic institutions.[72]
- In India, the research on medical materials, biomedical implants, and bioengineering-related areas is significantly funded by federal agencies, such as the DST, the Science and Engineering Research Board (SERB), the Department of Biotechnology (DBT) and the Indian Council of Medical Research (ICMR). In addition, CSIR, DRDO, and the Department of Atomic Energy (DAE) fund these research activities, mainly for the scientists working at the national laboratories affiliated with the respective organisations, and the academic researchers. DRDO has the Life Science Research Board (LSRB), which administers funding related to bioengineering areas. SERB's Materials, Mining & Minerals Engineering panel regularly invites proposals, funds selected projects, and administers their progress. According to data from the DST-Materials Panel, 28 projects worth INR 128 million (£1.28 million) were funded from 2014-2019. These projects are primarily on medical materials development with a focus on advanced manufacturing, microstructure-property correlation and biocompatibility of Mg-based biodegradable alloys, Ti-based alloys (e.g. Ti6Al4V), bio-ceramics/bio-glasses, and biopolymers/natural silk-based scaffolds. The outcomes of the funded projects address some of the existing clinical challenges in orthopaedics, dentistry, cartilage regeneration, and neurosurgical treatment.
- A similar review from DBT revealed funding of INR 408 million (£4.08 million) for research projects related to bio-design, bioengineering or biomedical engineering-related areas during the period 2014-2019. Among these projects, several, particularly relating to medical materials and devices, were worth INR 235 million (£2.35 million). All are aligned with DBT's mandate to facilitate:
  1. Medical technology (MedTech) innovation in India.
  2. Entrepreneurship and research leadership in biomedical engineering.
  3. MedTech products across a larger cross-section of the population with widespread affordability.
  4. Translational research involving multi-disciplinary teams (clinicians, researchers from academia/national labs and industry).
- The Small Business Innovation Research Initiative (SBIRI) scheme of the DBT is an enabling platform for the target organisations to realise their potential in terms of product and process development to take products and technologies to the market. The Biotechnology Industry Partnership Programme (BIPP) has the Academic Innovation Research (AIR) scheme to promote the development of proof-of-concept for a process or product by academia with or without the involvement of industry. BIRAC, together with the National Biopharma Mission, has initiated a technology transfer and commercialisation training programme intended to strengthen the overall capacity of the country in technology transfer.[73]

- Hyderabad-based IKP trust has funded 300 start-ups and innovators, of which 180 have been grant or seed funded.
- The Impacting Research Innovation and Technology Scheme (IMPRINT) was launched by the GoI in 2015 to provide solutions to the most relevant engineering challenges and to facilitate translating knowledge into viable technologies in ten selected domains, including advanced materials and healthcare (MHRD).
- The Andhra Pradesh MedTech Zone (AMTZ) group of institutions is the only comprehensible model in India providing innovation support, testing, validation, manufacturing infrastructure and policy support in the health technology sector, within one ecosystem. Following the success of AMTZ in Andhra Pradesh, several Indian states have plans to set up MedTech zones.

Research and Innovation Ecosystem

- During the last decade, Indian researchers from academia and national labs have established significant collaborations with industries and brought several clinicians to such collaboration platforms. Clinicians in different hospitals are pursuing clinical translational studies on medical materials and implants. Such collaborations have enabled the translation of the research outcomes to manufacture medical materials and functional implants. The technology of nano-bioceramics has been transferred from CSIR-NML to different companies, namely, Eucare Pharmaceuticals, Chennai; Surgiwear Pvt Ltd, Shajhanpur; and IFGL Pvt Ltd, Kolkata.
- Many medical materials and implants are being commercialised in India as an outcome of industry-academia interactions or technology transfer from academia to industry. Some of the leading companies in the medical materials sector are Tata Steel New Materials Business, TTK Chitra Heart Valve, Ants Ceramics, Synthera Biomedical Devices Pvt Ltd, Vidcare Innovations, Alfatek Technologies, Amace Technologies Pvt Ltd, Avay Biosciences, Arka Medical Devices Pvt Ltd, Indo MIM Pvt Ltd, Orthotech (Valsad, Gujarat), and Biorad Medisys.
- The Central Glass and Ceramic Research Institute (CGCRI), a research body under India's Council of Scientific and Industrial Research (CSIR), has developed a range of joint reconstruction prosthetics such as Al2O3-based ceramic femoral heads, zirconia-toughened alumina (ZTA)-based femoral heads, hydroxyapatite-based coatings for metallic implants, drug-eluting femoral stems, and HA/TCP based granules for the clinical domains of orthopaedic and/or dental surgery. New design concepts for integrated orbital implants were conceived, and manufacturing technology was developed to produce highly porous yet strong orbital implants using bioactive hydroxyapatite by CSIR-CGCRI scientists.
- A new generation of polymer-ceramic hybrid acetabular liner has been developed using three different manufacturing routes by IIT Kanpur, IIT Guwahati, and IISc Bangalore researchers. After establishing the acetabular liner manufacturing at INDO-MIM Pvt Ltd, Bangalore, these liners are now ready to be marketed as an acetabular component, integrated with a total hip joint replacement device with due regulatory clearance.
- IIT Delhi has employed biomechanical analysis and adapted conventional manufacturing processes to manufacture metallic dental implants, which were marketed in India in late 2019.

- In the area of piezoelectric perovskites, a research group in IIT BHU in Varanasi demonstrated the biocompatibility of sodium-potassium niobate [NaxK1-xNbO3 (x = 0.2 - 0.8), doped with Li]-based functionally graded composites, using a series of electro-mechanical, impedance spectroscopy and in vitro cellular studies.
- In the field of 3D bioprinting, a research group at IIT Delhi developed anatomically-relevant, phenotypically-stable cartilage constructs, using silk-gelatin bio-ink.
- Given different patient anatomy in Asian populations, effective customisation of medical materials implants is needed to meet the local requirements. The gradual rise in spinal disorders, including lumbar spine stenosis, degenerative discs, disc herniation, and spinal stenosis, among others, is one of the major contributing factors to the growth of the spinal implant market.

Research and Innovation in Antimicrobial Resistance Materials

Among the five categories of physical stimuli-based antimicrobial therapeutic approaches (photodynamic, ultrasonic, heat treatment, electrical, and magnetic), electrical and magnetic stimulation are recognised as promising strategies for enhancing antibacterial efficacy. Using experimental research, a team of researchers at IISc and IIT (BHU) demonstrated that electric field strength and exposure time are the most critical parameters that affect the resultant electrical-stimuli-based killing mechanism of action. The electro-permeabilisation resulting from the application of low-strength electric fields has been reported to enhance the efficacy of antibiotics and biocides needed to kill the bacteria in biofilms. One of the published studies from India reported how HA-Fe3O4-based magnetoactive composites can induce bactericidal properties. Another recent study established the critical role of pulse magnetic stimuli (up to 4T) in restricting the growth of Enterococcus faecalis strains, commonly implicated in root canal therapy treatment.

Despite the promise of the AMR technologies developed in India, it is a little far from clinical translation and therefore offers significant opportunities to the UK research community to provide expertise to the Indian counterparts.

Tata Steel Launches Medical Materials Business

Since 2017, Tata Steel New Materials Business (TSLNMB) has started venturing into the healthcare market by developing strategies for large-volume manufacturing of innovation-driven biomaterial products.

In 2020, Tata Steel announced global plans for healthcare and medical devices. The current focus of TSLNMB is to enter the market through hydroxyapatite and collagen-based products, and the medical materials team is working with two start-ups in these areas.

To further accelerate the journey into the medical materials sector, TSLNMB announced plans on 1 March 2022 to set up a world-class facility to produce medical material, and invest in a bio-ceramics start-up, Ceramat Pvt Ltd, through a wholly-owned subsidiary Tata Steel Advanced Materials.[75]

With the above plans, Tata Steel is expected to become one of the largest domestic medical materials players in the coming years.

Potential Areas of Collaboration

There is a strong and growing potential for India-UK collaboration in medical materials in the R&I activities mentioned in this report. Some of the ongoing research cited in the earlier section looks promising to secure more interest and investment and offer possibilities to create opportunities for collaboration and technology transfers or co-development of newer materials. Some of the key areas are a) metallic (such as titanium-based alloys) and non-metallic (such as PEEK (polyetheretherketone)) implant materials and fabrication technologies, b) hydroxyapatite and calcium phosphate-based materials; and c) gelatine and collagen for a range of medical use.

Case Studies: Collaborative Links in Medical Materials

- Prof Bikramjit Basu's group, previously at IIT Kanpur and currently at IISc, Bangalore, have a long successful collaboration with researchers from the Universities of Birmingham, Manchester, and Coventry in the field of medical materials, through funding from UK India Education Research Initiative and Global Challenge Research Funds.
- CSIR-NML, Jamshedpur researchers collaborated with the University of Cambridge in the field of magnetic nanoparticles for biomedical applications.
- SynThera Biomedical Pvt Ltd is India's first and foremost bioactive glass start-up. Their patented technology PoroSyn® represents another class of porous synthetic bone graft substitute products from bioactive phosphate glass materials for improved biomimesis and bone regeneration. SynOst® is a family of synthetic bone graft substitute products made from bioactive silicate glasses based on the inventor's prior work at University College London.
- Vidcare Innovations Pte Ltd, a start-up based in Pune, is poised to address the unmet clinical needs related to the diagnostic/screening of patients in rural India, particularly hypothyroidism in pregnant mothers. Their first product is based on the immunoassay solution that fulfils WHO's ASSURED (affordable, sensitive, specific, user-friendly, rapid and robust, equipment-free, and deliverable to end-users) criteria, based on integrated microfluidic chip technology. Vidcare received India Innovation Growth Programme 2.0 support, the UK Royal Academy of Engineering Leaders in Innovation Fellowship and the P&G Health Vision Award.[76,77]

Against this backdrop, it is felt that further collaboration through funded research projects would promote stronger links between researchers from India and the UK. Such collaboration would involve active participation from start-ups, micro, small and medium-sized enterprises and corporate sectors and many medical materials, which are currently at the TRL 3-4 range and can be made market-ready in the coming years.

Nanotech

Policy Landscape

Following the special initiative from DST, Nanomaterials: Science and Devices, launched in 2001-2002, GoI introduced the National Nano Mission, Phase-I, in 2007, with a budget allocation of INR 10 billion (£100 million). Three bodies, the Nano Mission Council (NMC), the Nano Science Advisory Group (NSAG) and the Nano Applications and Technology Advisory Group (NATAG), were set up to accelerate the infrastructure development for nanoscience and technology research, public-private partnerships, international collaborations, and academia-industry partnerships. In the Twelfth Five Year Plan (2012-2017), GOI approved a budget of INR 6.5 billion (£65 million) for the continuation of the Nano Mission, Phase-II, to promote more application-oriented R&D.[78]

Besides DST, various nanotechnology activities have been supported by the Department of Biotechnology, Ministry of Electronics and Information Technology, and various research and innovation bodies such as the laboratories and research establishments under the Council of Scientific and Industrial Research (CSIR) and the Defence Research and Development Organisation (DRDO). DST funded more than 500 research projects, undertaken mainly by national laboratories and academic bodies such as IISc and various IITs.

Research and Innovation Ecosystem

Most of the IITs, IISc and several academic bodies and national laboratories are working on a wide range of research areas in nanotechnology. Many of these projects are commissioned by industry players in the private sector. Some of the leading institutes and their research areas, especially with industry partners and activities of a mix of large companies and SMEs in the field of nanotechnology, are mentioned below.

- The Centre for Nano and Soft Matter Sciences (CeNS), IISc, Bangalore: Set up by GoI's Department of Science, CeNS has been working with many companies, including Tata Steel, Hindustan Petroleum, and Hind High Vacuum Company Pte Ltd. In October 2016, Tata Steel established the Tata Steel Advanced Materials Research Centre at CeNS, intending to shorten the lab-to-pilot phase of product development using nanomaterials, including graphene, for market applications. Tata Steel had collaborated in the past to develop anti-corrosion solutions using novel graphene technologies. CeNS is working in the areas of nano-soft composites, nanomaterials for energy applications, mask-less projection lithography systems, nanostructured hybrid transparent network electrodes on PET films and fabricating large-area nano-mesh coated transparent conducting glasses for smart window technology.
- The Centre for Research in Nanotechnology & Science (CRNTS), IIT, Mumbai: Their research areas include the use of nanotechnology in the areas of energy, health, environment, regenerative medicine, security, and sensors. CRNTS has worked with several overseas and domestic companies, including Intel, Hitachi, Tata Consulting Services, and the Indian Space Research Organisation.

- Aside from the above organisations, several Indian research bodies, funded mainly by DST, such as the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Nanomaterials Laboratory at the Tata Institute of Fundamental Research (TIFR), International Advanced Research Centre for Powder Metallurgy and New Materials, National Physical Laboratory, Institute of Chemical Technology and National Chemicals Laboratory, are undertaking a range of research and innovation projects in nanoelectronics, nano opto-electro-mechanical systems, nano-magnetics, and nano-biotechnology.
- Bharat Heavy Electricals' Centre of Excellence for Nanotechnology has a wide range of research activities in the field of nanotechnology, including nanomaterial-based electrodes for fuel cells, capacitors, batteries, material development for power plant components, carbon nanotube-based products like yarn for current conductors, and nano-coating to mitigate corrosion and bio-fouling problems in thermal power plant equipment.
- AD-NANO Technologies is manufacturing conductive inks, including graphene, graphite-based and carbon-nanotube.
- Using advanced nanotechnology, Mumbai-based Gegadyne Energy is developing next-generation batteries with high energy density.
- NoPo Nanotechnologies produce single-wall carbon nanotubes, which could be 100 times stronger than steel and 1,000 times more conductive than copper.

India and the UK have worked together on several events and trade missions on nanotechnology, supported by UKIERI, SIN and DIT. In 2014, UKIERI supported two projects involving the University of Hyderabad, the University of Surrey, and Queen's University Belfast, the Indian Institute of Science Education and Research, and Tata Steel, on various nanotechnology areas, including functional coatings, ZnO, graphene, and carbon nanotubes.[80]

Materials for Electrification and Energy Storage

At the COP 26 Climate Summit held in Glasgow, UK, in November 2021, Narendra Modi, the Prime Minister of India, outlined a target of 500 GW of non-fossil fuel-based energy generation by 2030 and a reduction of total projected carbon emissions by one billion tonnes by 2030. To achieve these targets, India needs to progress fast on creating substantial additional capacity for electricity grid storage and introduce a large number of EVs on roads, as India aims to have 30 per cent of new vehicle sales be electric by 2030. The introduction of EVs will result in a reduction in air pollution and also help reduce India's over-dependence on the import of crude oil.

The automotive industry has responded positively to the plan to move from internal combustion engine-based to electric vehicles. India accounts for a negligible share of the global energy storage solutions market. Still, rapid capacity addition and access to both mature and emerging technologies will offer a huge competitive advantage, not only in the energy storage solutions market for EVs and grid storage, but also in the consumer electronics sector. Supported by a range of policy initiatives, the EV sector is witnessing an increasingly robust pipeline of both domestic and foreign investment and energy storage solutions in advanced chemistry cells (ACC).

Policy Landscape

- NITI Aayog is implementing the National Mission on Transformative Mobility and Battery Storage to drive clean, connected, shared, sustainable, and holistic mobility initiatives. The mission focuses on creating a phased manufacturing programme (PMP) to support the setting up of large-scale, export-competitive integrated batteries and cell-manufacturing giga plants, as well as localising production across the entire EV value chain. To stimulate growth in domestic ACC-based energy storage manufacturing and to encourage the development of dedicated giga-scale (greater than 5 GWh/year in battery cell production) manufacturing capacities, GoI has invited bids for the scheme.
- India's Ministry of Heavy Industries and Public Enterprises (MHIPE) introduced the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles in India (FAME) policy in 2015. Its second edition, FAME II, launched in 2019 and valid until 31 March 2024, has provided an outlay of INR 100 billion (£1 billion) to boost the EV and charging infrastructure sector. Out of the total budgetary support, about 86 per cent of the fund has been allocated to create demand incentives for EVs. FAME II aims to generate demand by way of supporting 7,000 e-buses, 500,000 e-three-wheelers, 55,000 e-four-wheeler passenger cars (including strong hybrid) and one million two-wheelers.[81]

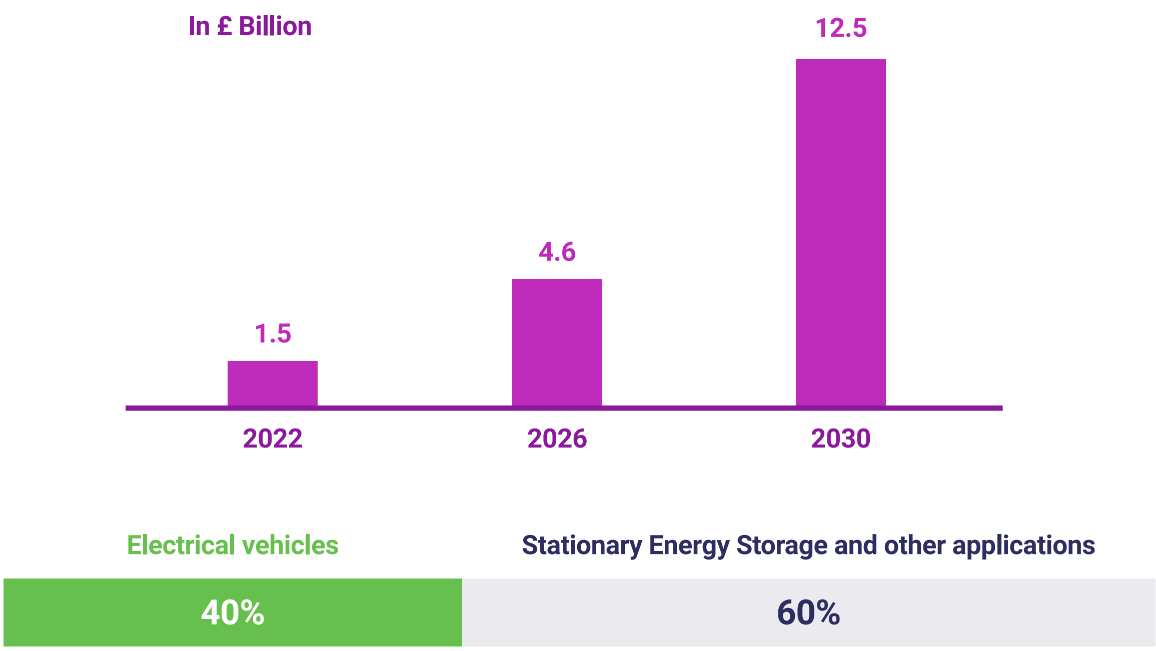
- MHIPE introduced PLI schemes for the automotive and components industry and the ACC sectors, with an allocation of INR 260 billion (£2.6 billion) and INR 181 billion (£1.8 billion), respectively.[82,83,84] For the ACC sector, the maximum incentive available is 20 per cent of the sale price of the cell or INR 2,000 (£20) whichever is lesser per KWh.[85] Four Indian companies, Reliance New Energy Solar, Ola Electric Mobility, Hyundai Global Motors Company and Rajesh Exports, have been selected to receive incentives under the PLI scheme for the ACC sector until the end of March 2022.[86]
- Aside from these key policy initiatives from NITI Aayog and MHIPE, several other GoI ministries and departments and various state governments have announced a range of incentives both on the demand and supply side to catalyse the fast growth of the EV sector and the creation of a robust EV system including a significant increase in ACC manufacturing capacity of global scale and size with the adoption of the latest technologies.

Research and Innovation Ecosystem

According to a recent NITI Aayog report[87], the annual market for stationary and mobile batteries in India could be £12.6 billion by 2030, with almost £10.1 billion from cells and £2.5 billion from pack assembly and integration. The projected demand for batteries could be met by five giga-factories in 2025 and 26 by 2030.

Indian battery market – 2030

£12.5 billion (CAGR ~28%)



*Source: NITI Aayog, RMI, and RMI India, Need for Advanced Chemistry Cell Energy Storage in India (Part I of III), February 2022 (projection for the accelerated scenario) and UKIBC estimates

Apart from the expected growth in EVs, the stationary energy storage (SES) market will grow to make the grid system ready for the addition of 500 GW of non-fossil fuel power by 2030. While the addition of 500 GW of green energy is the key demand driver for SES batteries, there will be additional demand from other application areas, such as the replacement of diesel generators for islands/standalone grids, power back-up for industries and use in remote equipment such as cell phone towers, mines, oil and gas, and defence installations. While the total ESS commissioned or under construction is only around 85 MWh, there is already a pipeline of projects amounting to 4.6 GWh. The NITI Aayog report projects that the cumulative capacity of stationary storage for grid support could reach 26 GW/104 GWh in the conservative scenario and has the potential to expand to nearly 65 GW/260 GWh by 2030 in the accelerated scenario.

The above scale of demand is expected to lead to large additional capacity and research efforts for new ACC technologies.

Advanced Chemistry Cell and Energy Storage Materials: Ongoing R&I Programmes

Advanced cell technologies include lithium-ion cells and chemistries better than lithium-ion available at commercial scale, such as sodium ion, zinc-air, and redox flow batteries.

DST is running a Materials for Energy Storage (MES) programme that supports R&D activities aimed at innovative materials for energy storage and building energy storage devices with enhanced output for multifunctional applications. The MES scheme has supported 77 projects with a total cost of INR 517 million (£5.17 million).[88]

Through another programme, the Material for Energy Conservation and Storage Platform (MECSP), DST supports two centres DST-IIT Delhi Energy Storage Platform on Batteries and DST-IISc Energy Storage Platform on Supercapacitors on a range of research on energy storage materials and technologies.

Several IITs, Indian Institutes of Science Education and Research (IISER) Pune, the International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI) Hyderabad, and the Council of Scientific and Industrial Research-Central Electrochemical Research Institute (CSIR-CECRI) too, are pursuing a wide range of research and innovation programmes on energy storage materials.

In July 2021, DST launched three compendiums collating information on ongoing research activities in India in the field of materials for energy storage. These compendiums are Hydrogen and Fuel Cell (HFC) 2018, Material for Energy Storage (MES 2018), and Material for Energy Conservation and Storage Platform (MECSP 2017).[89]

In the private sector, several companies ranging from large corporates such as Tata Chemicals to young start-ups such as Log9 are engaged in energy storage and EV battery research.

The energy storage sector is witnessing the entry of several leading Indian and overseas companies. Aside from investing in India, Indian companies are also looking at partnerships and collaborations with innovative overseas energy storage companies and start-ups. Notable development and major investment announcements are mentioned below.

India: Key Energy Storage Materials Projects and Announcements

- Several Tata Group companies are working together in the EV and energy storage space. While Tata Chemicals is leading in battery technology, Tata Power will bring its expertise in setting up charging stations. Tata Motors and Tata Auto Components are working on EVs and powertrain systems, and Tata Motor Finance will look after the vehicle financing options. TCS and Tata Technologies will provide support in the areas of software and design.[90]
- Tata Chemicals is creating an electrochemical platform to become one of India's leading players in the energy storage sector. The company is partnering with Indian R&D centres (like the Indian Space Research Organisation [ISRO], CSIR-CECRI, and the Centre for Materials for the Electronics Industry [C-MET]) for the indigenous development of battery materials actives, cells, and recycling. Tata Chemicals has committed an investment of INR 40 billion (£400 million) to set up an LiB plant in Dholera Special Investment Region (DSIR) in Gujarat.
- Tata Chemicals has established a process of recovering valuable materials from used LiBs. Recycling spent batteries provides valuable metals in the form of salts of lithium, cobalt, nickel, and manganese, along with byproducts like graphite, iron, copper, and aluminium. Their InsperiCo™ is the world's first branded recycled cobalt. The technology can be used for LiBs, including those based on lithium cobalt oxide, nickel manganese cobalt oxide, and nickel cobalt aluminium oxide.[91,92]
- While Tata Chemicals will cater to the energy storage needs of the EV sector, Tata Power will pursue opportunities for battery storage solutions for grid integration. They won India's first large-scale battery storage project in 2021 to build a 50 MW solar PV plant, co-located with a 50 MWh battery energy storage system at Phyang village in Leh, Ladakh.[93]
- Japan's Suzuki Motor Corp (SMC), Toshiba Corp, and Denso Corp are jointly investing INR 37.15 billion (£371.5 million) in the second phase of their battery venture in Gujarat's Hansalpur. The joint venture will manufacture 30 million lithium-ion cells per year by 2025, with a production capacity of more than 1 GWh. These batteries could be deployed in pure electric vehicles, hybrids, and electric two-wheelers.[94]
- Matter, a start-up electric mobility solutions and energy storage provider, recently planned to invest INR 15 billion (£150 million) over the next five years in Gujarat. Of this, INR 3 billion (£30 million) will be invested in energy storage, creating 4,000 jobs in the state over the next five years. [95]

- Reliance New Energy, a wholly-owned subsidiary of Reliance Industries, acquired Sheffield and Oxford-based Faradion in January 2022 for £100 million and plans to invest £25 million as growth capital to accelerate the commercial rollout. Faradion is the world leader in sodium-ion battery technology that provides low-cost, high-performance, safe, and sustainable energy. Its proprietary technology delivers leading-edge, cost-effective solutions for a broad range of applications, including mobility, energy storage, backup power, and energy in remote locations. Reliance will use Faradion's technology at its proposed fully integrated energy storage factory at the Dhirubhai Ambani Green Energy Giga Complex in Gujarat.[97]
- In March 2022, Reliance New Energy acquired Lithium Werks BV for USD 61 million, including funding for future growth. Headquartered in the Netherlands, Lithium Werks has offices, R&D and production facilities in the USA, Europe, and China. Lithium Werks is a leading provider of cobalt-free and high-performance lithium ferro-phosphate (LFP) batteries. With the recent rise in demand for LFP batteries, Lithium Werks with its experience in battery innovation and manufacturing for over 30 years, is reportedly uniquely positioned to take advantage of the global opportunities through its integrated portfolio of LFP solutions.[98]
- Ola Electric, the EV arm of the leading India rideshare company, Ola, is investing £100 million in Coventry, UK, in their Futurefoundry project. The R&D facility will focus on both EVs and batteries for EVs.[99]
- India's largest battery manufacturer, Exide Industries, is planning to set up a multi-gigawatt lithium-ion cell manufacturing plant. They are entering the ACC sector through their subsidiary, Exide Leclanche Energy (under the brand Nexcharge), in a joint venture with Leclanche SA, Switzerland. With its state-of-the-art R&D centre, the subsidiary aims to build LiBs and provide energy storage systems for the EV market and grid-based applications.[100] In March 2022, Exide Industries announced an investment of INR 60 billion (£600 million) to set up one of India's largest giga-scale advanced chemistry cell manufacturing facilities in Karnataka.[101]
- Indian battery major, Amararaja, invested in the European EV battery company, InoBat, in December 2021. InoBat has a LiB R&D facility and production line in Voderady, Slovakia. The project's next phase will focus on a manufacturing scale-up through several gigafactories planned across Europe and globally. The company is backed by a consortium of partners, including CEZ, a major European utility company, and Rio Tinto, the global mining giant. As a part of its global expansion plans, InoBat opened an office in the University of Warwick Innovation Centre in March 2022.[102, 103]
- The Chatterjee Group (TCG) is setting up a battery research laboratory in Kolkata at their Research Institute for Sustainable Energy, by TCG Centre for Research, Education, Science, and Technology (TCG Crest).[104]

Potential Areas for Collaboration

India and the UK have been working together on policy initiatives in the area of electrification and battery technologies. Some of the notable ongoing activities are mentioned below.

Current India–UK Links

- Focus areas of India-UK Roadmap 2030 include low-cost climate-appropriate technologies in e-mobility, battery manufacturing and innovations.
- The Joint UK-India Clean Energy Centre (JUICE) – a virtual joint centre partnership between UK and India focuses on energy storage among other areas.
- UK-NITI Aayog Electric Mobility Accelerator Programme focuses on the uptake of electric mobility and creating a supportive ecosystem.
- Knowledge exchange sessions between NITI Aayog and UK organisations on battery innovation.
- UK-India Joint Programme on Smart Power, Renewable Energy and Storage agreed in 2021.
- UK-India report on Advanced Cell Chemistry Battery Reuse and Recycling Market in India.

The Indian EV and energy storage companies and ongoing research by DST and GoI-supported laboratories are looking at a wide range of materials solutions for energy storage systems. The future areas of collaboration mainly comprise further work on LiBs with the existing and new Indian stakeholders and emerging research areas in alternative materials. In a strategic move towards energy storage materials, there is a conscious move to look at alternative material platforms which could offer similar or superior energy intensity. Some of the alternative battery chemistries that India could look at are summarised below.[105]

Energy Storage: Alternative Material Platforms

Battery type	Cathode material	Anode material
Li-Air, Mg-Air, Al-Air, Fe-Air, Zn-Air, lead flow batteries, vanadium flow batteries, Na-S, Li-S, thermal batteries, Na-NiCl2 (Zebra batteries), Ag-Zn, Mg-AgCl reserve batteries, ultra lead-acid batteries, lead – carbon, Li-Carbon, dual carbon	Lithium Nickel Cobalt Manganese Oxide (LiNiCoMnO2), Lithium Nickel Cobalt Aluminium Oxide (LiNiCoAlO2), Lithium Cobalt Oxide (LiCoO2), Lithium Manganese Oxide (LiMn2O4), Lithium Iron Phosphate (LiFePO4/C), Lithium Titanium Oxide, NiMn-Co-Al cathode materials, amorphous carbon, hard carbon, graphite (natural, synthetic graphite, Krish carbon), metal, organic frameworks -cathode and composite cathodes	Si–Graphite composite anodes, tin composite anodes, Li metal anodes, metal-organic frameworks

The Indian Prime Minister launched the National Hydrogen Energy Mission on 15 August 2021 to make India a green hydrogen hub. The mission has a target of producing 5 MT of green hydrogen by 2030 and building a supportive renewable energy capacity to facilitate the transition from fossil fuel to green hydrogen and green ammonia and meet India's commitments to renewable energy. About £80 million is expected to be invested over the next three years for infrastructure development and R&D on green hydrogen generation.

Several Indian companies such as Reliance Industries, Larsen & Toubro, the Adani Group and JSW Future Energy, have announced investments in the hydrogen sector. These projects will create demand for a range of materials solutions, including newer materials for hydrogen storage and composite (Type 3 and Type 4 cylinders) for use in hydrogen fuel cell vehicles.

Financial Landscape

GoI supports research and innovation activities through a range of government programmes, budgetary support to a network of research laboratories and autonomous bodies, and research grants. The central government held the largest share at 45 per cent of the total R&D expenditure in 2017-18, and the state governments accounted for 6.4 per cent.

The business sector accounts for 41 per cent of the total share in R&D expenditure, led by the private sector at 37 per cent and public sector industries at 4 per cent. The business sector's contribution to India's gross domestic expenditure (GERD) on R&D and the total number of personnel and researchers are among the lowest compared to the top ten economies in the world. India's Economic Survey 2021 has called for an increase in the private sector's investment in R&D.

In the financial year 2021-22, MoST was allocated INR 147.94 billion (£1.479 billion) which included an allocation of INR 60.67 billion (£606.7 billion) to DST, INR 52.24 billion (£522.24 million) to the Department of Scientific and Industrial Research and INR 35.02 billion (£350.2 million) to DBT. The MoST supports a range of programmes including science and technology institutional and capacity development, statutory and regulatory bodies (such as the Science and Engineering Research Board and Technology Development Board), and over 25 autonomous bodies.[106]

Key autonomous bodies supported by MoST in the advanced materials sector include CeNS, Bengaluru; International Advanced Research Centre for Powder Metallurgy and New Materials, Institute of Nano Science and Technology (INST), Mohali; and Satyendra Nath Bose National Centre for Basic Sciences.

Some of DST's support in the field of advanced materials include the National Mission on Nano Science and Technology, with a budget allocation of INR 6.5 billion (£65 million) during 2012-17, and the Materials for Energy Storage (MES) programme, with a budget allocation of INR 517 million (£5.17 million). As mentioned earlier, in the section on Biomaterials, the advanced material research for medical applications received support from a range of DBT initiatives.

GoI's PLI schemes in ten industrial sectors aim to make Indian manufacturers globally competitive, attract investment in the areas of core competency and cutting-edge technology; ensure efficiencies; create economies of scale; enhance exports and make India an integral part of the global supply chain. The PLI scheme for the automotive sector, INR 570 billion (£5.7 billion), and advanced chemical cell storage batteries, INR 181 billion (£1.81 billion), are of particular relevance to the advanced materials sector as these are driving growing investments, not only in new production facilities but also in several research initiatives.

GoI launched a variety of government programmes and incentives such as Make in India, Start-up India, and Skills India in the last decade aimed at boosting the domestic manufacturing sector, building a robust start-up ecosystem, and supporting Indian youths with vocational and market-relevant training programmes.

Aside from funding support from GoI, large companies have their R&D budgets, commission-sponsored research programmes at universities, and various R&I bodies, and support promising start-ups. For example, Tata Steel and the Aditya Birla Group run programmes to engage with promising start-ups. MaterialNEXT is a flagship event by Tata Steel, held annually by Tata Steel Advanced Materials Research centres to support innovative start-ups in the material science and technology domain and research initiatives outside Tata Steel.[107] As mentioned in the report, India's start-up ecosystem is the third-largest in the world, and it has a well-established network of angel investors, venture capital funds, and private equity players who have supported many start-ups in the early stages of their journey with seed capital and other assistance.

Recommendations and Next Steps

While the report has identified several research and innovation initiatives undertaken by Indian advanced materials companies, academia, and research bodies, and also looked at the supporting ecosystem, mainly driven by various GoI policies and funding support from the government and other sources, the following steps might help India and the UK to establish a deeper and closer engagement in the sector and lead to win-win research and business successes in the coming years.

1. Map specific R&I programmes of the top ten Indian companies and research bodies in each sub-sector along with their focus areas, size and trajectory of the research projects, budget, and gap in technology and research inputs.
2. Identify UK stakeholders who are well-placed to collaborate on bilateral R&I opportunities.
3. Design a supporting mechanism comprising India-UK events, workshops, missions, and creation of virtual groups for easy exchange of information with inputs from both GoI and the UK government, and participation of other stakeholders including industry bodies, large companies, and innovation/incubation centres in the two countries, and network of select venture capital funds and other potential investors.

Both the UK and India have considerable knowledge and expertise in the area of advanced materials. This market insight study concludes that there is interest in exploring UK-India collaboration partnerships. Additional research may highlight the scientific and economic benefit of a UK-India centre of excellence on key topics in advanced materials.

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