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AS A GLOBAL
SEMICONDUCTOR
LEADER

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TO ELECTRONIC
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BEFORE LEIBNIZ,
GREGORY AND
NEWTON

**THE PROMISE AND CHALLENGES OF
BRAIN-COMPUTER INTERFACES:
NEURALINK'S JOURNEY**

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Renewable Energy – A Solution to Rising Energy Demand

India, with its burgeoning population and rapid economic growth, faces a formidable challenge in meeting its ever-increasing energy demand. As one of the world's largest energy consumers, the country must balance the need for reliable power with the imperatives of sustainability and environmental protection. Renewable energy, with its promise of clean, abundant, and sustainable power, stands at the forefront of this balance, offering a viable solution to India's energy dilemma. India has made significant strides in the renewable energy sector over the past decade. With an ambitious target of achieving 450 GW by 2030, the country is positioned to become a global leader in renewable energy. Solar, wind, biomass, and small hydro are the primary renewable sources contributing to this target.

India has immense potential for solar energy, given its geographical location and abundant sunlight. The Indian government has promoted the development of large-scale solar parks and Ultra Mega Solar Power Projects. These initiatives aim to create solar hubs with capacities ranging from 500 MW to over 2 GW.

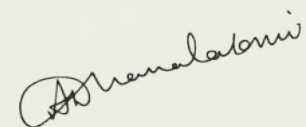
Wind energy is another cornerstone of India's renewable energy strategy. The country's coastline and topography provide favorable conditions for wind power generation. India is currently the fourth-largest wind power producer globally, with significant investments in onshore and offshore wind farms.

Biomass and small hydro projects are crucial for providing decentralized energy solutions, particularly in rural areas. These sources help in reducing dependency on fossil fuels and mitigating environmental impacts. India's diverse agricultural landscape offers ample biomass resources, while numerous rivers and streams present opportunities for small hydro developments.

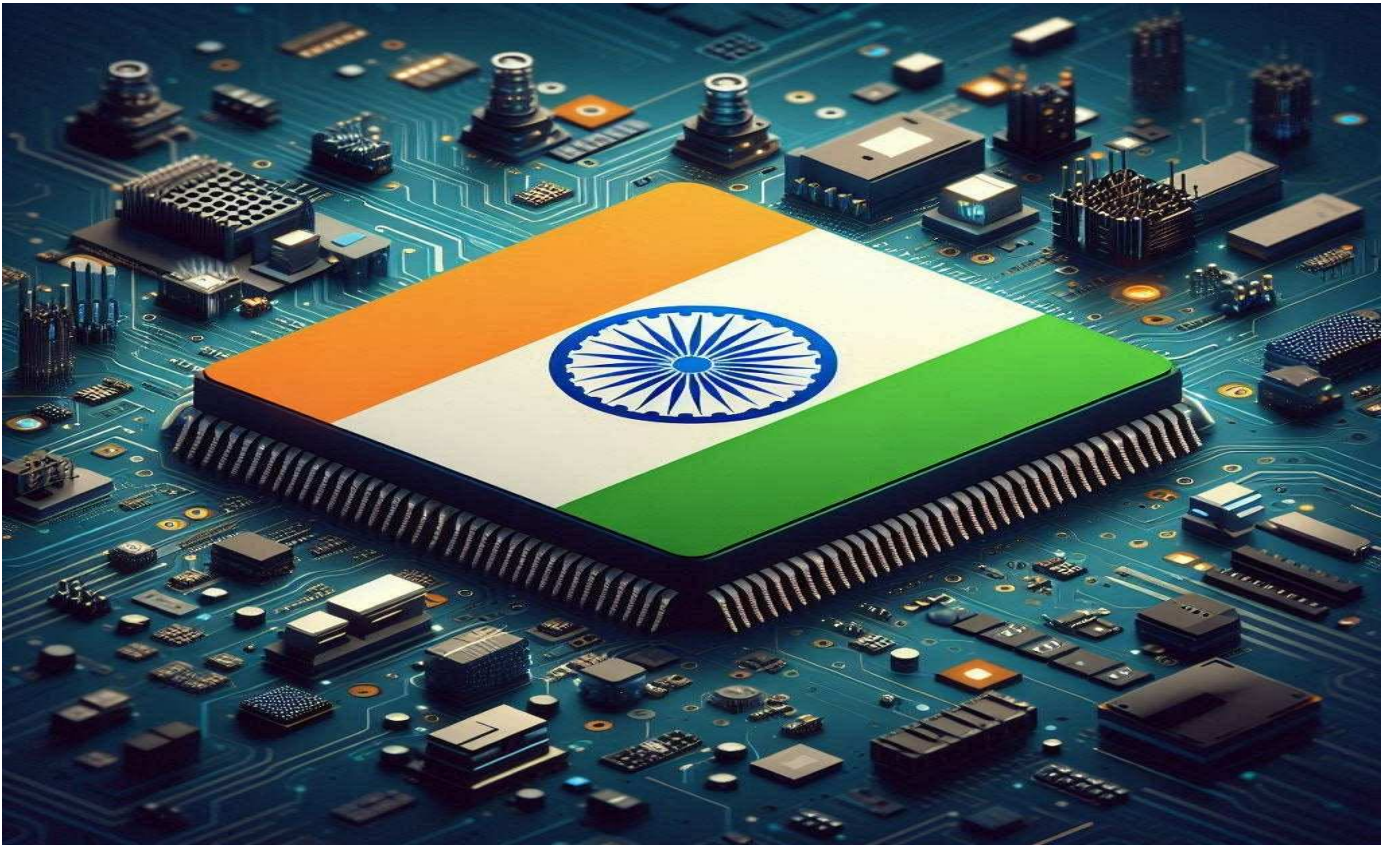
One of the most significant advantages of renewable energy is its minimal environmental impact. Unlike fossil fuels, renewable sources generate power without emitting greenhouse gases or other pollutants. This is crucial for India, which grapples with severe air pollution and its associated health risks. Transitioning to renewable energy helps reduce the carbon footprint and combat climate change. Renewable energy enhances India's energy security by reducing dependence on imported fossil fuels.

Despite its potential, the renewable energy sector in India faces several challenges. These include high initial investment costs, technological barriers, grid integration issues, and policy and regulatory hurdles. Addressing these challenges requires a multifaceted approach. Attracting investment in renewable energy projects is crucial. Innovative financing mechanisms, public-private partnerships, and international collaborations can help mobilize the necessary capital. Continuous research and development are vital for advancing renewable energy technologies. Emphasis on innovation can lead to cost reductions, efficiency improvements, and better grid integration. Building robust infrastructure for renewable energy, including storage solutions and smart grids, is crucial for ensuring reliability and efficiency. Investments in transmission and distribution networks are also necessary to integrate renewables seamlessly into the national grid.

India's renewable energy sector holds the key to solving the country's energy demand challenges while promoting sustainability and environmental stewardship. By harnessing the power of the sun, wind, biomass, and hydro, India can pave the way for a cleaner, greener, and more prosperous future. The commitment to renewable energy not only addresses immediate energy needs but also ensures long-term energy security and economic growth, positioning India as a global leader in sustainable development.



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INDIA POISED TO EMERGE AS A GLOBAL SEMICONDUCTOR LEADER

After gaining independence in 1947, India had undergone nearly two centuries of de-industrialization under the British Raj. This prolonged period of economic stagnation left the country with minimal industrial infrastructure. It was said that after independence, India was not able to manufacture even a single needle domestically, highlighting the severe industrial decline. However, India has since made significant strides, emerging as a digital powerhouse, a nuclear state, and a leader in space technology. Looking ahead,

India is poised to become a significant force in electronics as well. To position India as a global hub for Electronic System Design and Manufacturing, the Union government has launched a comprehensive program. This initiative includes the establishment of the India Semiconductor Mission (ISM), recently approved by the cabinet. The ISM aims to foster a sustainable semiconductor and display ecosystem in the country, offering attractive incentives for companies engaged in Silicon Semiconductor Fabs, Display Fabs, Compound Semiconductors/

Silicon Photonics/Sensors (including MEMS) Fabs, Semiconductor Packaging, and Semiconductor Design. Its primary objective is to solidify India's global standing in Electronic System Design and Manufacturing.

The future is intricately intertwined with technology, yet the question persists: which technological marvel will lead the way? It could be things like Artificial Intelligence, Nanotechnology, Robotics, Internet of Things (IoT), Image Processing, Augmented Reality, or something else we haven't thought of yet. But what's at the

heart of all these new technologies? The answer is “**Electronics**”. The invention of the ‘Transistor: a semiconductor device’ at Bell Labs in California, USA, stands as the most fundamental achievement of the 20th century. This groundbreaking innovation has not only revolutionized the entire world but also paved the way for the unprecedented digital revolution we are currently witnessing. The semiconductor industry is a key sector in the world economy, producing electronic components used in a variety of products ranging from aeroplanes to computers, from missiles to refrigerators, from space stations to bread toaster and many more. Nowadays, it is nearly impossible to imagine a device without semiconductor inside. In fact, any device with an on/off switch has one or often dozens or hundreds of semiconductor devices inside.

What exactly the Semiconductors are?

Semiconductors, crucial to nearly every modern electronic device, bridge the conductivity gap between conductors like copper and insulators like glass. Examples include silicon, germanium, gallium arsenide, and elements near the “metalloid staircase” on the periodic table. What makes semiconductors uniquely valuable in today’s technological landscape is their ability to alter and control their conducting properties through a process known as doping, where impurities are introduced into the crystal structure. This capability allows for the creation of semiconductor junctions when differently doped regions coexist within the same crystal. The behavior of charge carriers—such as electrons, holes, and ions—at these junctions forms the basis of essential electronic components like diodes and transistors. Such devices have found wide application because of their compactness, reliability, power efficiency, and low cost.

Semiconductors are the foundation of modern technology, allowing for the creation of complex electronics and communication systems. These small yet powerful components are the backbone of technology, enabling the functionality of smartphones, televisions, and automobiles. Beyond

consumer electronics, semiconductors are essential in advanced applications such as artificial intelligence, space exploration in rockets, automation in robots, and sophisticated systems in military weapons. Their ubiquity and versatility make semiconductors indispensable in our increasingly digital world, driving innovation and efficiency across diverse industries. As technology advances, the demand for semiconductors will rise, making them an essential part in defining the future.

What exactly the Semiconductor chips are?

Semiconductor chips, commonly known as “chips”, are not to be confused with the snack food enjoyed by children. They are tiny electronic components made of semiconductor material such as silicon. Semiconductor chips contain integrated circuits (ICs) that consist of numerous electronic components, including transistors, diodes, resistors, and capacitors, all fabricated onto a small piece of semiconductor material. These serve as the “brains” of electronic devices, performing a wide range of functions such as processing data, storing information, and controlling the operation of electronic devices. There are various types of semiconductor chips designed for different purposes. Some examples are Microprocessors - used in computers and mobile devices for data processing, Memory Chips - used for storing data temporarily (RAM) or permanently (ROM, flash memory), Application-Specific Integrated Circuits (ASICs) - customized chips designed for specific applications like AI, automotive systems, or telecommunications, System-on-Chip (SoC) - Chips that integrate all components of a computer or other electronic system into a single chip. These semiconductor chips are manufactured through a complex process called semiconductor fabrication (or semiconductor manufacturing). This involves creating layers of materials and patterning them to form transistors and interconnections using techniques like photolithography, etching, and deposition.

In short, semiconductor chips are

the foundational elements of modern electronics, playing a crucial role in powering the digital revolution. They are indispensable in various aspects of contemporary life, driving innovation across industries and supporting advancements in technology.

History of Semiconductor Industry in India

The history of the semiconductor industry in India is marked by several key milestones and challenges. In 1984, the Indian government established Semiconductor Complex Ltd. (SCL), a crucial step forward in domestic semiconductor manufacturing. SCL was supported by licensing agreements with international firms like Hitachi, AMI, and Rockwell. Concurrently, efforts were made to establish a National Silicon Facility, which attracted interest from companies in the United States and East Germany. Metkem Silicon Ltd., in collaboration with BEL (Bharat Electronics Limited), set up polysilicon facilities in Mettur, Tamil Nadu, marking India’s early foray into semiconductor production.

By the late 1980s, India had carved out a niche in producing older-generation semiconductor chips, exporting these while importing cutting-edge chips from companies like Intel, Motorola, and Rockwell for local computer use. However, India began to lose its manufacturing lead in subsequent decades. A devastating fire at the SCL complex in Chandigarh in 1989 dealt a severe blow, limiting its production mainly to chips for India’s Space Research Organisation (ISRO). Economic liberalisation policies from 1991 onwards opened the floodgates to cheaper semiconductor imports, further challenging India’s semiconductor ambitions. Promised government subsidies, especially in electricity, failed to materialize, hindering the semiconductor manufacturing ecosystem.

In 2007, the Indian government announced its first Semiconductor Policy aimed at attracting significant investment and establishing fabrication

units. AMD and Intel explored setting up facilities in India, with AMD's SemIndia consortium even securing a licensing agreement with AMD Inc. However, these plans faced setbacks due to policy delays, stringent investment requirements, and global corporate restructuring. Intel's ambitious plans also faltered amidst logistical and regulatory challenges.

The last significant push in India's semiconductor policy occurred in 2013-14, with the issuance of Letters of Intent (LOIs) to consortiums like Hindustan Semiconductor Manufacturing Corporation (HSMC) and Jaiprakash Associates Ltd. Despite these efforts, HSMC's permit was eventually canceled in 2019 due to prolonged paperwork delays.

Looking back to the 1960s, Indian companies began their semiconductor journey by manufacturing germanium semiconductors. During this time, discussions with industry pioneers such as Fairchild Semiconductors explored the possibility of establishing Asia's first integrated circuit (IC) unit in India. Bharat Electronics Ltd. (BEL), a public sector undertaking (PSU) under the Ministry of Defence (MoD), acquired germanium and silicon technology to produce semiconductor devices. BEL, alongside Hindustan Aeronautics Ltd. (HAL), another PSU under the MoD, has remained a significant presence in India's semiconductor sector, focusing exclusively on serving the defence industry.

Overall, while India has made strides in semiconductor technology, its journey has been marked by challenges including infrastructure gaps, policy inconsistencies, and global market dynamics. Moving forward, the focus remains on revitalizing efforts to bolster indigenous semiconductor capabilities and attract global investments to propel India's position in the global semiconductor landscape.

India Semiconductor Mission (ISM)?

The India Semiconductor Mission (ISM) is an initiative launched by the Government of India to promote and

boost the semiconductor and electronics manufacturing industry within the country. The ISM was launched in 2021 with a total financial outlay of Rs76,000 crore under the aegis of the Ministry of Electronics and IT (MeitY), Government of India. It is part of the comprehensive program for the development of sustainable semiconductor and display ecosystem in the country. The programme aims to provide financial support to companies investing in semiconductors, display manufacturing and design ecosystem. It

The 21st century is a technology-driven century and cannot be imagined without Electronics Chips Made in India, Designed in India and Manufactured in India

also promotes and facilitate indigenous Intellectual Property (IP) generation and encourage, enable and incentivize Transfer of Technologies (ToT). ISM will enable collaborations and partnership programs with national and international agencies, industries and institutions for catalyzing collaborative research, commercialization and skill development.

The ISM is focused on three key areas:

Chip design: The ISM is supplying funding to Indian startups and companies to develop their own chip designs.

Chip manufacturing: The ISM is working to attract foreign companies to set up chip manufacturing facilities in India.

Semiconductor testing and packaging: The ISM is providing funding to Indian companies to develop their capabilities in semiconductor testing and packaging.

Furthermore, India Semiconductor Mission (ISM) encompasses a range of objectives aimed at boosting

the semiconductor and electronics manufacturing sector in India. These include promoting investment by incentivizing both domestic and foreign investments and fostering a favorable business environment. Capacity building efforts focus on enhancing indigenous research and development capabilities across semiconductor technologies, encompassing design, fabrication, testing, and packaging. Skilling and talent development initiatives aim to cultivate a proficient workforce through targeted training programs and partnerships with educational institutions. Infrastructure development initiatives support the establishment of semiconductor fabrication units and advanced manufacturing facilities, complemented by robust logistical networks. The mission also entails policy formulation to bolster sectoral growth, encompassing technology adoption, intellectual property rights, and export facilitation. Additionally, ISM encourages global collaboration by fostering partnerships with international semiconductor firms, research bodies, and governments to leverage global expertise and technological advancements, reinforcing India's position in the global semiconductor landscape.

The India Semiconductor Mission is part of India's broader strategy to achieve self-reliance (Atmanirbhar Bharat) in critical technologies, reduce import dependence, create employment opportunities, and foster innovation and economic growth in the semiconductor and electronics sectors. It underscores India's ambition to become a significant player in the global semiconductor industry and contribute to the advancement of digital and technological capabilities domestically.

Why to Promote Semiconductor Industry in India?

Semiconductor is the heart of modern economics. In today's technological world, when almost everything revolves around electronic gadgets, one cannot overstate the importance these microchips hold. By promoting the semiconductor industry, India can strengthen its technological capabilities and reduce dependency on imports, enhancing national

security and sovereignty. Furthermore, semiconductor industry is a high-value sector with significant economic potential. Promoting this industry can attract investments, create jobs across various skill levels, and contribute to GDP growth through manufacturing, research and development, and exports. India's own consumption of semiconductors is expected to cross USD 80 billion by 2026 and to USD 110 billion by 2030, demonstrating an impressive compound annual growth rate (CAGR) of 20.1% from 2023 to 2032. There are not many countries in the world that manufacture these chips. The Semiconductor industry is currently dominated by the United States of America, Taiwan, South Korea, Japan and the Netherlands. Germany is also an emerging producer of integrated circuits (ICs). In all this, it might actually be a good idea for India to get on the bus early. However, recent developments and strategic initiatives have catapulted India into the spotlight. The nation has made significant strides in fostering a conducive environment for semiconductor manufacturing and research and development.

Moreover, the semiconductor sector in India presents a diverse array of job opportunities across multiple domains and skill levels, offering significant potential for the country's youth. India is set to generate an impressive 800,000 to 1 million jobs in semiconductor industry over the next five years, highlighting sustained growth and promising prospects within the semiconductor ecosystem. Opportunities abound in Research and Development (R&D), where professionals engage in designing, developing, and testing semiconductor materials, devices, and processes, encompassing silicon design, circuit design, and process engineering. Manufacturing and Production roles focus on overseeing production processes, ensuring quality control, and managing supply chains within semiconductor fabrication facilities (fabs) and assembly and testing units. Design and Engineering positions involve creating integrated circuits (ICs) and systems-on-chip (SoCs) tailored for applications spanning consumer electronics, automotive systems, and telecommunications. Sales

and Marketing careers revolve around promoting semiconductor products, managing client relationships, and staying abreast of market dynamics and customer requirements. Testing and Validation specialists ensure the reliability and performance of semiconductor products through meticulous testing protocols and quality assurance measures. Application Development roles center on crafting software and applications leveraging semiconductor technologies, such as embedded systems, IoT devices, and AI applications. Technical Support and Services encompass providing comprehensive customer support, troubleshooting semiconductor products, and delivering technical solutions to clients. Lastly, Management and Leadership opportunities encompass strategic planning, business development, and leadership roles pivotal to steering semiconductor companies toward continued growth and innovation.

The semiconductor industry is a dynamic and growing field, and there are many opportunities for career advancement. With the right skills and experience, youth can have a successful career in semiconductors in India. In essence, developing indigenous semiconductor capabilities reduces reliance on imports for critical technologies. It enables India to address national priorities, support domestic industries, and leverage technology for socio-economic development.

Recent Developments in India

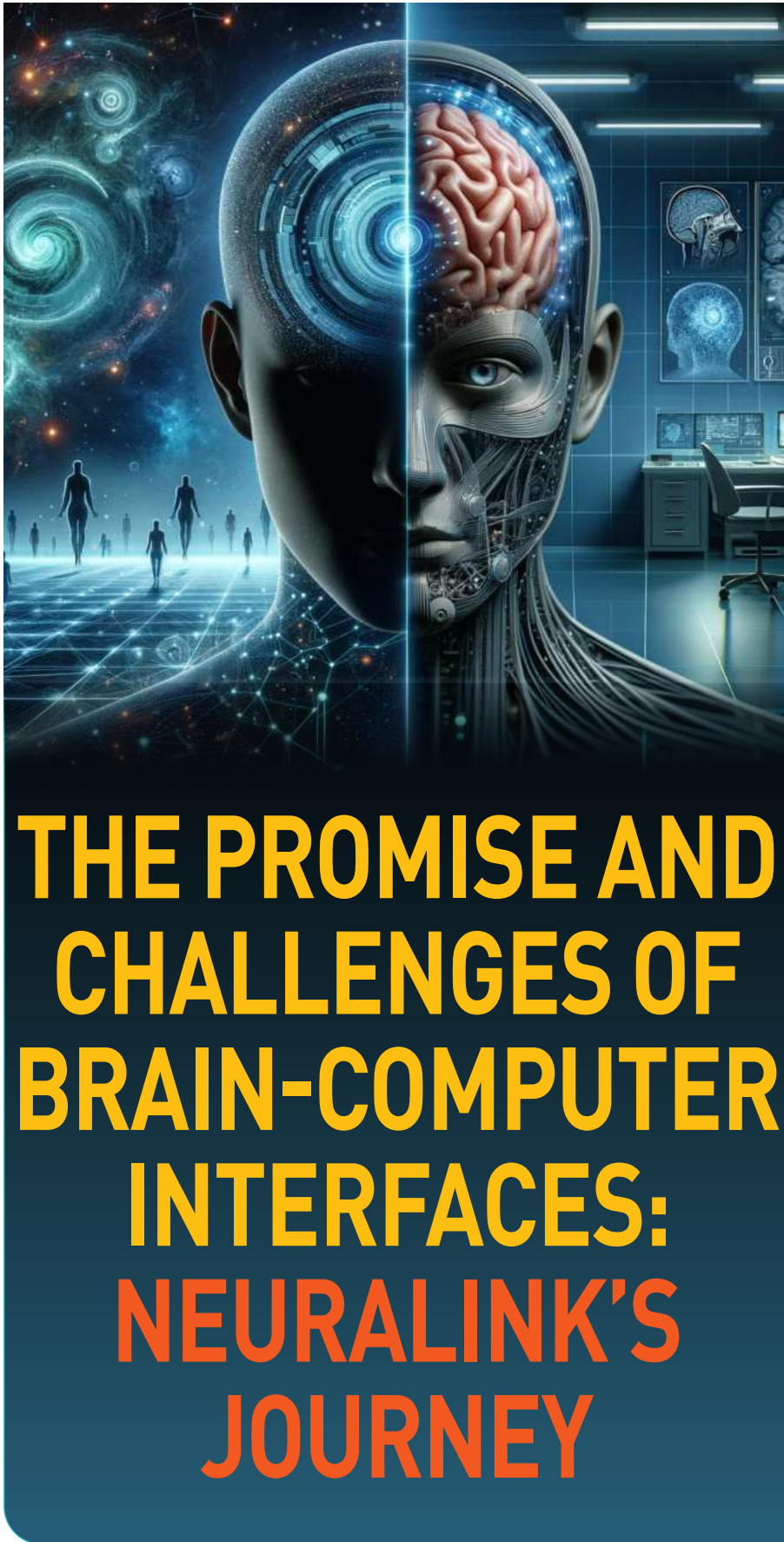
On March 13th, 2024, in a significant stride forward, Prime Minister of India laid the foundation stone of Tata-Powerchip Semiconductor Manufacturing Corp's chip fabrication unit, valued at Rs 91,000 crores, in Dholera, Gujarat. This endeavor positions Dholera as India's pioneer in commercial semiconductor fabrication faculty in the country. Additionally, Prime Minister inaugurated the CG Power-Renasas Outsourced Semiconductor Assembly and Test (OSAT) facility, worth Rs 7,600 crores, in Sanand, Gujarat, and the Tata OSAT unit, valued at Rs 27,000 crores, in Morigaon, Assam. These facilities will go a long way in boosting the semiconductor ecosystem in the country,

besides generating thousands of jobs in the semiconductor industry. Together, these three projects signify India's official entry into the domain of commercial chip fabrication units.

Final Thoughts

India's remarkable transformation an economy hampered by colonial deindustrialization to a technological powerhouse highlights its resilience and strategic vision. The launch of the India Semiconductor Mission (ISM) symbolizes a pivotal moment in this journey, aiming to position India as a global leader in Electronic System Design and Manufacturing. With significant investments and initiatives in semiconductor technology, India is set to play a crucial role in shaping the future of global electronics, fostering innovation, and driving economic growth. The ambitious vision of "Make in India" and "Indian Semiconductor Mission" is set to pave the way for a prosperous & Viksit Bharat@2047. Overcoming technological challenges, building a skilled workforce, ensuring a resilient supply chain, and adopting sustainable practices are crucial for realizing this vision. With a growing domestic market, government support, and a thriving ecosystem, India is well-positioned to make its mark in the semiconductor industry. As the world looks to India as a potential semiconductor leader, the nation's commitment to innovation and self-reliance will define the future of this vital industry. Government of India's emphasis on "Made in India" and "Designed in India" chips underscores their pivotal role in advancing India's journey toward modernization and self-reliance. The road ahead is promising, with electronics at the heart of technological advancement, reinforcing India's emergence as a significant force in the digital age.

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THE PROMISE AND CHALLENGES OF BRAIN-COMPUTER INTERFACES: NEURALINK'S JOURNEY

Imagine a world where the boundaries between the human mind and technology no longer exist. A world where you can effortlessly control computers, smartphones, and a myriad of digital devices using nothing but your thoughts. This may sound like a scene straight out of a science fiction movie, but with the rapid advancements in brain-computer interface (BCI) technology, this futuristic scenario is quickly becoming a reality.

Brain-computer interfaces are revolutionary systems that enable direct communication between the human brain and external devices. By bridging the gap between the biological and the digital, BCIs open up a whole new realm of possibilities for human-machine interaction. This ground-breaking technology has the potential to transform the way we live, work, and interact with the world around us.

At the forefront of this technological revolution is Neuralink, a company founded by visionary tech entrepreneur Elon Musk. With a team of brilliant scientists and engineers, Neuralink is pushing the boundaries of what is possible with BCI technology. Their mission is to develop a seamless interface between the human brain and artificial intelligence, unlocking unprecedented opportunities for human enhancement and exploration.

The implications of BCI technology are far-reaching and profound. For individuals with neurological conditions or physical disabilities, BCIs offer the hope of regaining lost capabilities and improving their quality of life. Imagine a quadriplegic person being able to control a computer cursor or a robotic arm using only their thoughts, or a person with a speech impairment communicating effortlessly through a brain-controlled speech synthesizer.

But the potential applications of BCIs extend far beyond the medical field. As the technology advances, BCIs could revolutionize the way we interact with computers and other digital devices. Instead of relying on traditional input methods like keyboards and touchscreens, we could control our devices with the power of our thoughts. This could lead to more intuitive and efficient human-

computer interaction, transforming the way we work, learn, and entertain ourselves.

Moreover, BCIs could open up new frontiers in human cognition and creativity. By directly interfacing with the brain, BCIs could enable us to access and manipulate information in ways that were previously unimaginable. We could potentially enhance our memory, learning abilities, and problem-solving skills, pushing the boundaries of human intelligence to new heights.

However, the development of BCI technology also raises important ethical and societal questions. As we delve deeper into the realm of brain-computer interfaces, we must carefully consider the implications for privacy, security, and individual autonomy. We must ensure that the technology is developed and deployed in a responsible and transparent manner, with the well-being of individuals and society as a top priority. As we stand on the brink of this technological revolution, it is clear that brain-computer interfaces have the potential to reshape our world in profound ways. The journey ahead is filled with both excitement and challenges, but one thing is certain: the future of human-machine interaction is upon us, and it is a future that promises to be truly transformative.

In the following sections, we will explore the inner workings of BCI technology, delve into the work being done by companies like Neuralink, and examine the ethical and societal implications of this rapidly evolving field. Join us on this fascinating journey as we uncover the promise and challenges of brain-computer interfaces and catch a glimpse of the future that awaits us.

Neuralink's First Human Implant

In a remarkable milestone for brain-computer interface technology, Neuralink made headlines in January 2024 when they announced the successful implantation of their first BCI device in a human patient. This historic event marked a significant step forward in the field of neural engineering and offered a glimpse into the transformative potential of BCIs for individuals with neurological conditions.

The patient, Noland Arbaugh, a 30-year-old man, had been living with



Figure 1. A person wearing a BCI device.

quadriplegia since a tragic diving accident in 2016 left him paralyzed from the neck down. For eight years, Arbaugh had faced the challenges and limitations that come with severe spinal cord injury, with little hope of regaining his lost motor functions. That is, until he became the first person to receive Neuralink's cutting-edge BCI implant.

Neuralink's device, a marvel of miniaturization and precision engineering, is no larger than a coin. This tiny, yet powerful device was surgically implanted into Arbaugh's brain by a team of highly skilled neurosurgeons. The implantation process involved carefully threading microscopic wires, each thinner than a human hair, into specific regions of Arbaugh's brain. These wires, equipped with an array of sophisticated sensors and electrodes, would serve as the bridge between Arbaugh's neural activity and the external computer system.

The surgery itself was a delicate and complex procedure, requiring the utmost precision and expertise. Neuralink's surgical robot, designed specifically for this purpose, played a crucial role in ensuring the accurate placement of the implant and minimizing the risk of complications. The robot's advanced imaging and guidance systems allowed the surgical team to navigate the intricate landscape of the brain with unprecedented accuracy, ensuring optimal positioning of the device.

Just a couple of months after the surgery, Arbaugh began to experience the

extraordinary capabilities of the Neuralink device. In a series of demonstrations that captivated the world, Arbaugh showcased the incredible potential of BCI technology. Using nothing but his thoughts, he was able to effortlessly control a computer cursor, navigating it across the screen with remarkable speed and precision. He could type on a virtual keyboard, composing messages and emails using only his mind. Even more impressively, Arbaugh was able to engage in complex tasks such as playing video games, a feat that would have been unimaginable just a few months prior.

For Arbaugh, the impact of the Neuralink implant was nothing short of life-changing. "Before this, I really had nothing to look forward to," he reflected, his voice filled with emotion. The diving accident had robbed him of his independence and left him feeling trapped within his own body. But with the Neuralink device, Arbaugh discovered a newfound sense of freedom and possibility. "This device has completely changed that. It's given me a new lease on life," he declared, his eyes shining with hope and determination.

Arbaugh's experience serves as a powerful testament to the immense potential of BCIs to restore capabilities and enhance the quality of life for individuals with paralysis or other neurological conditions. The ability to control digital devices using the mind alone opens up a world of possibilities for communication, work, entertainment, and personal autonomy. For the millions of people

worldwide living with spinal cord injuries, stroke, or neurodegenerative diseases, the implications of this technology are nothing short of revolutionary.

Challenges and Controversies

As with any technology, the development and advancement of BCI through Neuralink have been accompanied by a range of challenges and controversies. While the achievements in this field are undeniably impressive, it is crucial to acknowledge and address the concerns that have been raised along the way.

One of the most significant controversies surrounding BCI research has been the use of animal testing in the development of these devices. Animal rights activists and some members of the scientific community have expressed deep concerns about the welfare of animals, particularly primates, involved in BCI experiments. Allegations have surfaced suggesting that the rushed timelines and pressure to achieve rapid results have led to unnecessary suffering and even deaths of animals implanted with prototype devices.

These concerns are not to be taken lightly. The ethical treatment of animals in scientific research is a fundamental principle that must be upheld. While the companies involved in BCI development have vehemently denied any wrongdoing, the allegations of mistreatment cannot be ignored. It is essential that rigorous ethical guidelines and oversight are in place to ensure that animal testing is conducted in a humane and responsible manner, minimizing any potential harm or distress.

Beyond the ethical concerns surrounding animal testing, the development of BCI technology has also faced significant technical challenges. The complexity of the human brain and the delicate nature of neural interfaces present numerous hurdles that must be overcome. One such challenge was highlighted in the case of a patient whose BCI device experienced a malfunction, with some of the tiny wires retracting from their brain. This incident led to a decline in the device's performance and raised concerns about

the long-term stability and reliability of BCI implants.

The retraction of the wires underscores the inherent risks associated with directly interfacing with the human brain. The brain is a highly complex and sensitive organ, and any foreign object introduced into its delicate structure carries the potential for complications. While tweaks to the software have since restored and even improved upon the initial capabilities of the device, this incident serves as a stark reminder of the need for ongoing research



and development to ensure the safety and efficacy of BCI technology.

Despite these setbacks and challenges, the commitment to advancing BCI technology remains strong. Researchers and companies alike recognize the immense potential of this technology to transform the lives of individuals with neurological conditions and disabilities. Efforts are underway to actively recruit additional trial participants, particularly those with quadriplegia, to further study and refine BCI systems.

The recruitment of trial participants is a critical step in the development process, as it allows for the collection of valuable data and insights into the real-world applications of BCI technology. By working closely with individuals who stand to benefit the most from these devices, researchers can gain a deeper understanding of the needs, challenges, and opportunities associated with BCI use. This collaborative approach ensures

that the technology is developed in a manner that is responsive to the actual requirements and experiences of the end-users.

As more data is collected and analyzed, there is hope that BCIs will become increasingly reliable, safe, and accessible to a wider range of individuals in need. Ongoing research and development efforts aim to address the technical challenges, refine the surgical procedures, and optimize the algorithms that interpret neural signals. By continuously improving the technology and incorporating feedback from trial participants, the goal is to create BCI systems that are robust, user-friendly, and capable of seamlessly integrating into the daily lives of users.

The Future of BCIs

As we stand at the precipice of a new era in human-machine interaction, the future of BCIs holds unimaginable potential. The rapid advancements in this field have already begun to reshape our understanding of what is possible, and the vision for the future is nothing short of awe-inspiring. At the forefront of this technological

revolution is Elon Musk, whose bold and ambitious vision for the future of BCIs has captured the imagination of scientists, technologists, and the general public alike.

Musk envisions a world where BCIs enable a profound “symbiosis” between the human brain and artificial intelligence. This symbiotic relationship, he believes, will unlock unprecedented possibilities for human enhancement and exploration. By directly linking the vast computational power and knowledge of AI systems with the intuitive and creative capabilities of the human mind, we could achieve a level of cognitive and perceptual augmentation that far surpasses our current limitations.

One of the most tantalizing potential applications of advanced BCIs is the restoration of sensory and motor functions for individuals with disabilities. Imagine a future where a blind person could regain sight by having visual information directly stimulated in their visual cortex. Through a sophisticated BCI system, captured

visual data could be processed and translated into patterns of neural activity that the brain can interpret as visual perception. This would open up a world of possibilities for individuals who have lost their sight, enabling them to navigate their surroundings, recognize faces, and appreciate the beauty of the world around them.

Similarly, BCIs could provide a means for paralyzed individuals to regain control over their muscles and restore their ability to walk. By bridging the gap between the brain's motor commands and the muscles, a BCI system could bypass damaged or severed spinal cord connections. This

way we learn, work, and solve problems, ushering in a new era of accelerated human progress.

The possibilities for communication and collaboration could also be transformed by advanced BCI technology. Imagine being able to communicate with others through direct brain-to-brain interfaces, bypassing the need for verbal or written language. Thoughts, emotions, and ideas could be transmitted seamlessly between individuals, fostering a level of understanding and empathy that transcends our current modes of communication. This could break down barriers of language, culture, and even

the synergy between human and artificial intelligence could propel us into a new era of unprecedented progress.

While these visions of the future may seem like science fiction, the rapid pace of advancement in BCI technology suggests that they may be closer than we think. As BCIs become more sophisticated, miniaturized, and user-friendly, they could potentially be integrated into wearable devices or even become a standard part of human augmentation. Imagine a future where a BCI headset is as common as a smartphone, allowing individuals to seamlessly interface with digital systems and enhance their cognitive capabilities on-demand.



would allow paralyzed individuals to control robotic exoskeletons or even their own muscles through direct neural stimulation. The impact on quality of life and independence for these individuals would be truly transformative.

Beyond restoring lost functions, BCIs also hold the potential to enhance and augment human cognitive abilities. Imagine being able to download and upload information directly to and from your brain, effectively expanding your memory capacity and knowledge base. With a BCI-enabled “neural prosthesis,” you could instantly access vast repositories of information, acquire new skills and languages effortlessly, and process complex data with unprecedented speed and efficiency. This could revolutionize the

species, enabling us to connect with one another on a fundamentally deeper level.

Perhaps one of the most exciting and far-reaching applications of BCIs is the potential to merge human intelligence with artificial intelligence. By directly interfacing the human brain with AI systems, we could harness the unique strengths of both biological and artificial cognition. The intuitive and creative capabilities of the human mind could be combined with the vast computational power and data processing abilities of AI, creating a symbiotic partnership that could tackle the most complex challenges facing humanity. From solving global problems like climate change and disease eradication to pushing the boundaries of scientific discovery and space exploration,

Conclusion

The field of brain-computer interfaces is rapidly advancing, and the successful implantation of Neuralink's device in a human patient marks a significant milestone. The experiences of Noland Arbaugh demonstrate the immense potential of BCIs to restore capabilities and improve the quality of life for individuals with neurological conditions. However, the journey ahead is not without challenges. Technical hurdles, ethical concerns, and societal implications must be carefully navigated as BCI technology continues to evolve. The development of non-invasive, wearable BCIs may offer a more accessible and less risky avenue for certain applications, and India's growing BCI ecosystem is well-positioned to contribute to this progress. As we stand at the cusp of a new era in human-machine interaction, it is crucial to approach the development and deployment of BCI technology with a balance of excitement and caution. By engaging in open dialogue, fostering responsible innovation, and prioritizing the well-being of individuals and society as a whole, we can harness the immense potential of BCIs to transform lives and shape a better future for all.

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WASTE NOT WANT NOT: New Approaches to Electronic Waste Management



“Waste isn’t waste until we waste it”- WILL.I.AM

Electronics have revolutionised our lives, making it easier to connect through video calls and text messages, saving lives in hospitals with MRT and CT scans, and empowering minds in classrooms with educational videos and endless information. They drive progress and open up new possibilities in every aspect of our daily routines, making them indispensable. However, the world is now grappling with a significant challenge related to the disposal of electronic waste or e-waste, with billions of tons discarded annually.

E-waste consists of discarded electronic devices such as smartphones, tablets, laptops, televisions, monitors, desktops and solar panels, presenting both challenges and opportunities. Traditionally, most of this e-waste ends up in landfills, posing environmental risks due to toxic materials

like lead, cadmium, and mercury. Ideally, we can save up to 70 per cent of these discarded items, recovering valuable raw materials without releasing harmful fumes into the environment.

Unfortunately, most people are unaware of e-waste and its associated risks. In our pursuit of the latest models, driven by consumerism, we frequently buy new gadgets without considering the fate of our old devices. Companies often release new models with minor technology upgrades to boost profits, encouraging this cycle. Have we ever thought about what happens to our old devices after we discard them? They become e-waste. With the increasing population and increasing electronics consumption, e-waste production is reaching unprecedented levels.

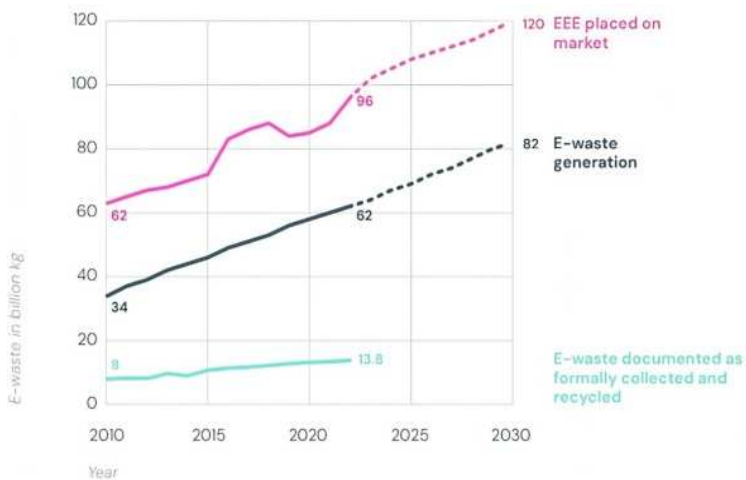
Therefore, it is essential to find innovative ways to reduce and recycle e-waste, raise awareness and promote sustainable practices.

Global e-waste crisis: How big is the problem?

According to a 2024 report by Global E-waste Monitor, the annual global production of e-waste is increasing by 2.6 million tonnes each year, estimated to reach 82 million tonnes by 2030. This represents a 33% rise from the 2022 total of 62 million tonnes. Europe tops the list in e-waste generation, followed by Oceania (Australia, Papua New Guinea, New Zealand, etc.), America, Asia and lastly, Africa.

E-waste requires careful management primarily because of its hazardous composition. Electronics contain high amounts of lead, cadmium and mercury, which are severely harmful to humans and animals if exposed for longer periods of time or in higher concentrations.

Secondly, e-waste contains some quantity of gold, silver and copper, which are economically valuable metals, and should be safely extracted. Due to poor



Source: UNITAR

management practices, e-waste is not treated separately and instead dumped in landfills along with organic and inorganic wastes. This waste can percolate the soil through leaching and contaminate the groundwater, which is used for drinking and other purposes, ultimately leading to hazardous consequences. For example, if present in the soil for a long time, mercury can be converted by microbes into methylmercury, a potent neurotoxin for humans and animals.

A pressing issue is the management of garbage collectors who handle these discarded electronics. Many of these workers (including child labourers) are unaware of the harmful effects of e-waste and do not take necessary precautions while working in landfills. They sift through piles of scrap, sorting out circuit boards, batteries and capacitors. Some of this e-waste is submerged in chemical solutions or burned to extract minute quantities of valuable metals like gold and copper.

This lack of awareness and proper safety measures exposes workers to toxic, poisonous chemicals and carcinogens, leading to various diseases and highlighting the need for urgent management by the authorities. It is essential to educate and protect these workers to ensure their safety and health while handling e-waste.

Challenges in E-waste management

The life cycle of electronics consists of three phases: pre-consumption (mining,

manufacturing, sales and distribution), consumption (use and repair), and post-consumption (recycling, refurbishment, waste management, etc.). The recycling process is usually taken into consideration in the last phase only. However, it is equally important in the first two phases. Currently, there is a gap in the management of these three phases for most electronic items.

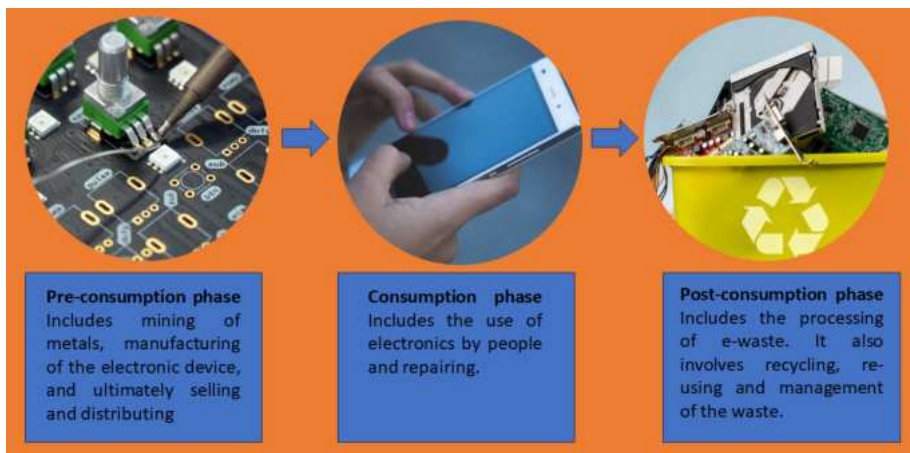
Secondly, recycling e-waste is a major challenge. The metals and compounds in e-waste are not in their pure state, making the recycling process difficult. Additionally, the health of workers involved in recycling is at risk due to exposure to potentially carcinogenic and toxic compounds.

Lastly, there is a huge gap between regulations and their implementation.

The guidelines for new projects are well documented but lack strict enforcement and implementation. For example, the Indian government has banned the import of e-waste from abroad, yet adherence to these guidelines is inconsistent.

Nowadays, there is a growing awareness about the environmental impact of e-waste and the potential treasures hidden within it. This awareness should encompass two aspects: understanding the impact of e-waste on our planet and taking responsibility for its proper disposal. From salvaging valuable materials to exploring innovative recycling methods, a movement is gaining momentum aimed at reducing waste and maximising the lifespan of our tech devices.





Success Stories: Effective E-Waste Management around the World

If we start designing products with the concept of circular design in mind - creating reusable, repairable and recyclable products to minimize waste - we can make tremendous advancements in the e-waste management challenge. Moreover, using these techniques during the second phase of a product's life cycle by repairing used items or using discarded parts as raw materials for some other products can significantly reduce waste production.

Many people in various countries are making a difference by salvaging old solar panels. Instead of throwing them away, these panels are being repurposed to generate solar power. This not only helps the environment but also saves money by avoiding the purchase of new panels. For example, in Hamburg, Germany, people are installing renewable power plants on private balconies using used solar modules. This helps reuse old modules instead of shredding them.

Balcony and roof solar panels in Germany. Source: International Centre for STEM Education

Engineer Martin Wilke is now focusing on recycling old solar panels. Organisations like SoliSolar assemble balcony power plants that connect to the grid, generating up to 600 watts of power. A normal photovoltaic module must operate for two years to produce the electricity used for its production. But a second-hand module

provides an immediate climate benefit. Two modules with 600 watts of power can provide enough electricity to run a washing machine and refrigerator, saving more than 100 euros (₹ 8,941) per year.

Another solution is to rent electronics instead of buying them. This way, devices can be used for longer, and when they're no longer needed, they can be repaired or recycled instead of being thrown away. The issue of e-waste extends beyond Europe, with countries like India facing significant challenges in managing e-waste.

Initiatives like Commown in France focus on sustainable electronics by offering rental services for devices like smartphones and laptops. They provide repairs and replacements to extend the lifespan of devices, thereby reducing the overall demand for new gadgets. Similarly, in Germany, efforts are made to switch

to renting durable electronics to reduce waste.

In Germany, a start-up has developed a process to extract valuable raw materials like silver and silicon from old solar panels. This helps reduce the need to import raw materials and lessens dependency on new resources. Many companies are also improving the work conditions of the e-waste recyclers. Swiss entrepreneur Dea Wehrli is creating safe spaces for workers to dismantle hazardous waste.

Beyond local initiatives, many countries have adopted large-scale management involving the construction of eco-industrial parks and implementing extended producer responsibility programmes. These initiatives correspond to the making of 'smart' cities, which offer core infrastructure, ensure a decent quality of life for citizens, and maintain a clean and sustainable environment).

India's E-Waste Management: Challenges and Innovations

India produced 1.6 million metric tons of e-waste in 2021-22, with much of it being dismantled and recycled in Seelampur, Delhi, by around 50,000 pickers working without regulations, and the remaining left unprocessed.

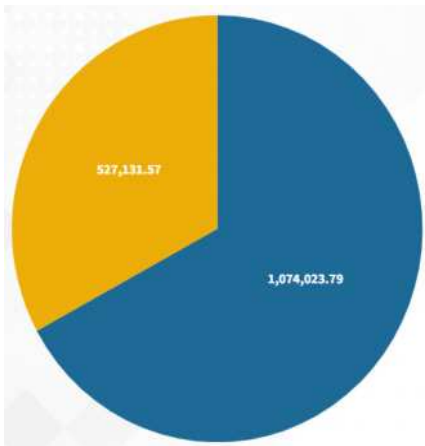
In a country like India, the concept of an Eco-Industrial Park (EIP) for large-scale management is a promising one. Think of an ecological system where one organism's waste becomes another's resource. This principle is the inspiration behind the



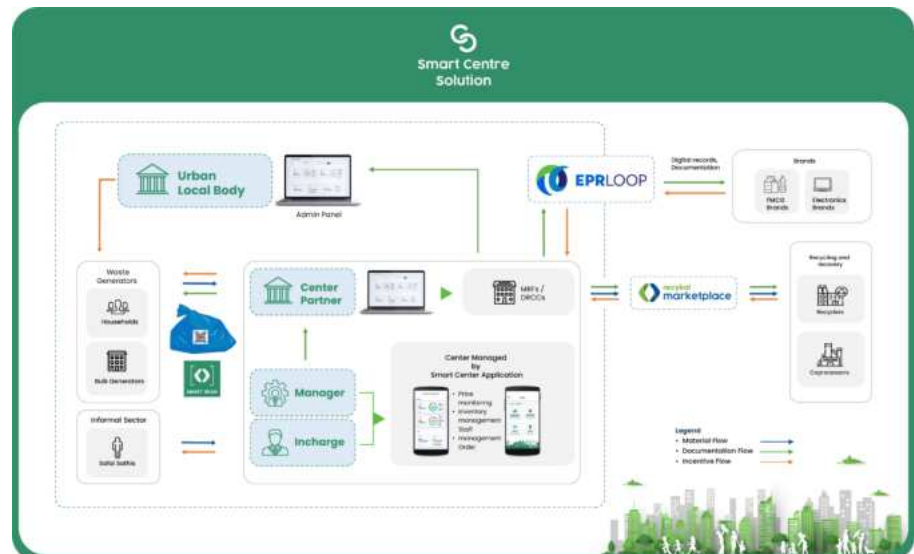
Balcony and roof solar panels in Germany. Source: International Centre for STEM Education

As of 2021-22 (in tonnes)

■ Unprocessed ■ Collected and processed



Source: Government reply to Parliament. Chart by Sreedev Krishnakumar



How Recykal and Smartskan work. Source: Recykal

creation of eco-industrial parks. These parks act as hubs of businesses where a waste to one is a useful raw material to another. These parks aim to produce minimum waste through collaboration and sustainability.

In 2011, recognising the need for e-waste management, the Indian government introduced the e-waste (Management and Handling) rules. These rules proved to be a significant landmark, especially with the incorporation of Extended Producer Responsibility (EPR). EPR took a considerable leap in the e-waste management issue by prompting manufacturers to ensure safe disposal of electronic and electrical products once they are no longer usable.

Despite these efforts, a significant amount of e-waste is still improperly managed by the unofficial industry, which has detrimental effects on the environment and human health. Understanding the severity of the situation, the Indian Government declared the new E-Waste (Management) Rules (2022) in November 2022, which took effect on April 1, 2023. Notably, the new regulations cover over 100 types of electronic equipment in seven major categories. But, more work needs to be done, especially to get more thorough coverage under EPR. Additionally, 'PM Surya Ghar: Muft Bijli Yojana' is a new initiative announced on February 13, 2024, to promote

sustainable development and provide free electricity to households through rooftop solar systems. The scheme aims to benefit one crore households by providing up to 300 units of free electricity each month.

It is also suggested that EIP and EPR be combined to form E-Waste Recycling Parks (ERPs). By sharing infrastructure, reducing transportation costs, and fostering inter-industry linkages, ERPs will make recycling more cost-effective. Additionally, they can boost regional economic development by creating jobs, localising production and consumption, and promoting cooperation between formal and informal sectors. The Rajasthan government plans to build an ERP in the state.

The Deposit Refund System (DRS) is another effective strategy for managing e-waste in cities. The system requires one to deposit a fee at the time of purchase and receive a small refund upon returning the used appliance. This sustainable approach is easy on the customer's pocket and channels e-waste into a recycling stream. Smartskan, an initiative by Recykal

(an Indian tech start-up) uses scanning technology where a person can fill up the e-waste in a bag containing a QR code. A collection vehicle will come to collect the bag. This bag will then be scanned to get details of the waste and this information will be stored in a local database making it completely transparent and traceable. Following this, the waste will be processed and sold to a recycler, and the empty bags with QR codes will be free to use again.

Clean e-India, a joint initiative by Attero and East Delhi Municipal Corporation (EDMC), picks up e-waste from homes and offers a cash reward. This initiative ensures eco-friendly processing and promotes awareness through social media, hoardings in public places,



Clean E India pick-up truck. Source: Clean-e India

collection drives and toll-free numbers. It also rewards consumers fairly through digital payment systems, encouraging participation in sustainable practices while contributing to environmental conservation efforts.

As discussed above, the informal sector, including waste pickers and recyclers, plays a crucial role in handling e-waste in India. Efforts are underway to integrate these workers into the formal waste management system by providing training, equipment, and support. Public-Private Partnerships (PPPs) are one such effort, with the government collaborating with private companies to enhance e-waste management practices. For example, the Maharashtra government has partnered with e-waste recycling firms to set up collection centres across various cities, aiming to streamline the recycling process and protect the environment.

Apart from this, corporations like Volvo, Kodak, Electrolux, and Xerox have implemented innovative green production practices aimed at reducing e-waste generation.

E-waste to E-wow

Not only companies and NGOs, but even individuals are also making profits from e-waste recycling. A scarp fair is organised every year in South Bishnupur, West Bengal, where old and used items are sold at low prices. Sellers collect scrap



A girl using a 'used' treadmill in Bhangra Mela. Source: Reuters

items throughout the year, repair them and then sell them at the fair or Bhangra mela. Typically, a new smartphone in India costs between ₹16,000-17,000 and ₹25,000, but in the mela, used mobile phones are available for as little as ₹1500 to ₹500.

In Delhi, projects like EcoWork aim to improve working conditions for those involved in e-waste recycling, aiming to make the process safer and more efficient.

Conclusion

Despite all these approaches and efforts by companies and governments, the world is still grappling with the

tremendous generation of e-waste and poor management thereof. Overcoming the challenges and implementing effective strategies to integrate different initiatives is the only way to tackle this problem. The Global E-waste Monitor 2024 report suggests that the percentage of e-waste that is officially collected and recycled is expected to decrease from 22.3% in 2022 to 20% by 2030. This decline indicates a growing gap between recycling efforts and the rapid increase in global e-waste production. The importance of sustainable practices in the electronics industry and the potential for innovative solutions to mitigate the environmental and social impacts of e-waste should be highlighted. The potential for innovative solutions, such as improving e-waste recycling technologies, enhancing producer responsibility programs, and fostering public awareness, is crucial. By integrating these strategies, we can work towards a more sustainable future, reducing the harmful effects of e-waste on our planet and society.

Interesting Facts about E-Waste

1. Every year, the world produces approximately 40 million tons of electronic waste. To put it in perspective, that's equivalent to discarding 800 laptops every second.

2. Up to 80% waste generated in the US is transported to Asia for processing.

3. Cell phones and other electronic devices are rich in valuable metals such as gold and silver. Each year, Americans discard phones that collectively contain more than \$60 million worth of these precious metals.

4. Recycling 1 million laptops conserves enough energy to power 3,657 homes in the US for one year.

5. E-waste is the fastest growing solid waste stream in the world

6. Only 17.4% of e-waste is known to be collected and properly recycled.

7. Only 78 countries have any form of legislation for dealing with e-waste.

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MADHAVA'S ACHIEVEMENT IN MATHEMATICS: MILESTONES REACHED BEFORE LEIBNIZ, GREGORY AND NEWTON

Madhava of Sangamagrama, a 14th-century mathematician from Kerala, India, stands as a pivotal figure in the history of mathematics. His ground-breaking work laid the foundation for the Kerala School of Astronomy and Mathematics, significantly advancing mathematical knowledge in medieval India.

Madhava's contributions spanned various mathematical domains, including infinite series, trigonometry, and early forms of calculus. His discoveries, particularly in infinite series and power series expansions for trigonometric functions, predated similar European developments by nearly three centuries. Notable among these was the infinite series for π (π), now known as the Madhava-Leibniz series.

The Kerala School, building on Madhava's work, flourished for several generations, producing significant advancements in mathematics and astronomy. The rediscovery of Madhava's contributions in modern times has led to a re-evaluation of the global history of mathematics, highlighting the important role of Indian mathematicians in the development of advanced mathematical concepts. Figure 1 shows the depiction of Madhava.

Early Life and Background

The life of Madhava of Sangamagrama remains largely shrouded in mystery.

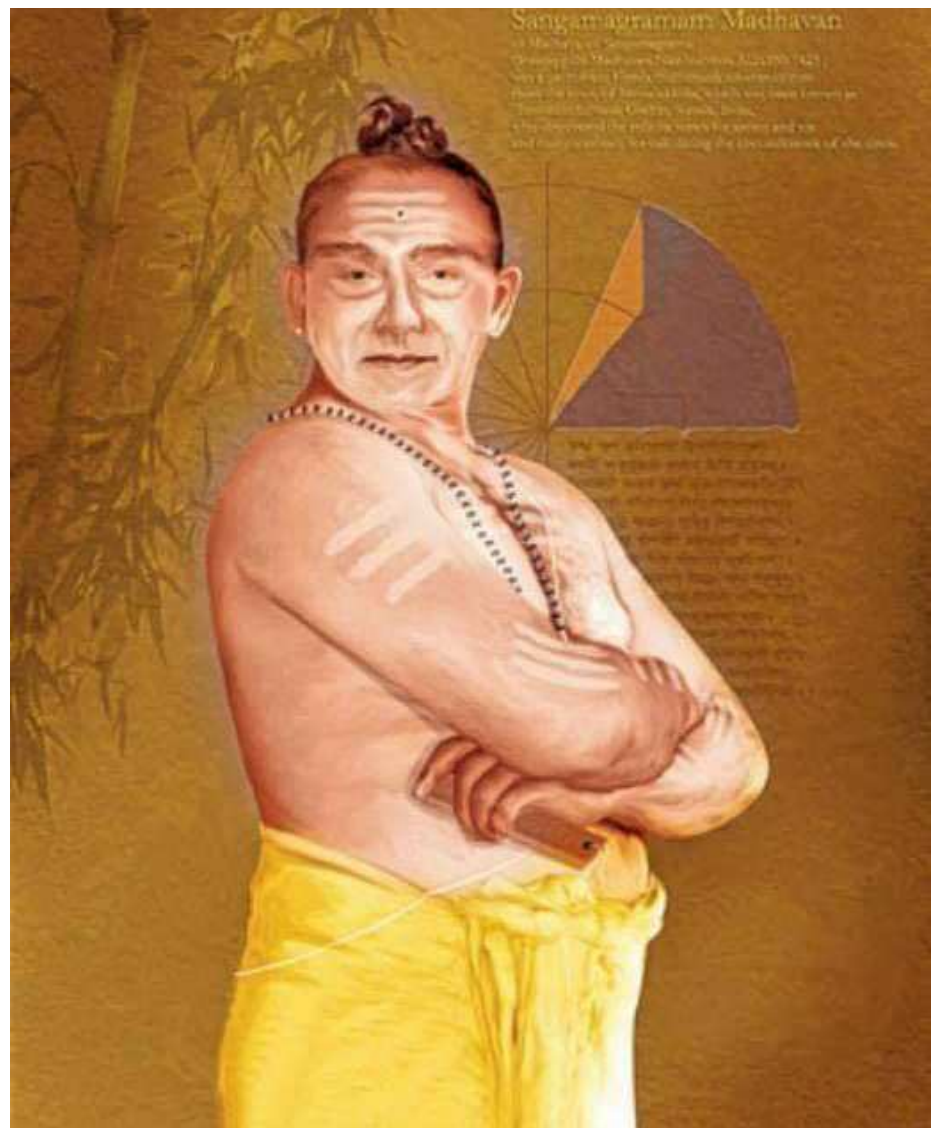


Figure 1. Madhava.

Historians have had to rely on scattered references in various manuscripts to piece together information about this remarkable mathematician.

A manuscript from the Oriental Institute in Baroda refers to Madhava as “Mādhavan vēṅvārōhādīnām karttā ... Mādhavan Ilaññippalli Emprān.” The term “Emprān” suggests Madhava may have belonged to the Emprāntiri community, a group of Brahmins in Kerala.

Madhava’s residence is believed to have been called “Ilaññippalli.” In his work “Vēṅvārōha,” Madhava himself mentions being born in a house named “bakūḷādhīṣṭhita vihāra,” which is Sanskrit for “Ilaññippalli.” The name refers to the Mimusops elengi tree, known as “Ilaññi” in Malayalam and “Bakūḷa” in Sanskrit. Some historians have attempted to link this to existing houses near Irinjalakuda, but these connections are considered tenuous due to lack of linguistic similarities.

Madhava is often referred to as “Sangamagrama Madhava” by later writers. The location of Sangamagrama is debated. While many scholars believe it to be Irinjalakuda, about 70 kilometers south of the Nila River and Cochin, this association is primarily based on the presence of the Koodalmanikyam Temple, whose deity is called Sangameswara (Lord of the Confluence).

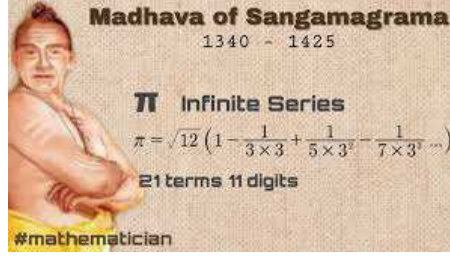
An alternative theory suggests that Sangamagrama might refer to Kū allūr, a town on the southern banks of the Nila River. The name Kū allūr translates directly to Sangamagrama in Sanskrit, and it’s located at the confluence of the Nila and Kunti rivers. This theory is supported by the existence of a Nambudiri family named Kūtallūr Mana near Kudallur, known for maintaining a Gurukulam specializing in Vedanga studies. The fact that the only known manuscript of Madhava’s “Sphuṭacandrāpi” was found in the Kūtallūr Mana collection adds weight to this hypothesis.

Given these factors, some historians propose that Madhava’s ancestors might have migrated from the Tulu region to Kudallur a generation or two before his birth, settling in a house called Ilaññippalli. However, the exact location of this house remains unknown.

Mathematical Contributions

Infinite Series

Madhava’s most significant contributions were in the field of infinite series. He discovered the power series expansions for sine, cosine, and arctangent functions, a breakthrough that would not be replicated in Europe until the time of James Gregory in the 17th century.



One of his most famous discoveries is the infinite series for (pi), now known as the Madhava-Leibniz series:

which he obtained from the power-series expansion of the arc-tangent function. He also gave few corrections terms for the error after computing the sum up to terms. We provide most accurate form for computing as below:

He also provided a more rapidly

converging series by transforming the original infinite series of , obtaining the infinite series as below:

By using first 21 terms to approximate , he obtained a value of to 3.14159265359 which is correct to 11 decimal places.

Power Series

He also developed a power series which acts as expansion for many trigonometry functions.

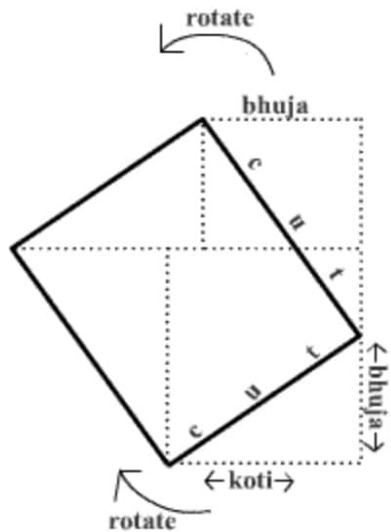
All three series were later discovered in 17th century Europe. The sine and cosine series were rediscovered by Issac Newton in 1669. The arctan series was rediscovered by James Gregory in 1671 and Gottfried Leibniz in 1673. The arctan series is now considered as Gregory’s series. The arctan series for 1 is now called as Leibniz’s series. Later, mathematicians such as Nilakantha Somayaji (1444 – 1544 CE) and Jyeshthadeva (1500 – 1575 CE) in their writing established that Madhava had done give explicit statements for his own works. The *Yuktidipika* commentary of *Tantrasamgraha* (also known as *Tantrasamgraha-vyakhya*) written by mathematician Sankara Variar (1500 – 1560 CE) explained how Madhav’s series work.

श्रेष्ठं नाम वरिष्ठानां हिमाद्रिवेदभावनः ।
तपनो भानु सूक्तज्ञो मध्यमं विद्वि दोहनम् ॥ १ ॥
धिगाज्यो नाशनं कष्टं छन्नभोगाशयाम्बिका ।
मृगाहारो नरेशोयं वीरो रणजयोत्सुकः ॥ २ ॥
मूलं विशुद्धं नाळस्य गानेषु विरळा नराः ।
अशुद्धिगुप्ता चोरश्रीः शङ्कुकर्णो नगेश्वरः ॥ ३ ॥
तनुजो गर्भजो मित्रं श्रीमानत्र सुखी सखे ।
शशी रात्रौ हिमाहारौ वेगज्ञः पथि सिन्धुरः ॥ ४ ॥
छाया लयो गजो नीलो निर्मलो नास्ति सत्कुले ।
रात्रौ दर्पणमभ्राङ्गं नागस्तुङ्गनखो बली ॥ ५ ॥
धीरो युवा कथालोलः पूज्यो नारीजनैर्भगः ।
कन्यागारे नागवल्ली देवो विश्वस्थली भृगुः ॥ ६ ॥
तत्परादिकलान्तास्तु महाज्या माधवोदिताः ।
स्वस्वपूर्वविशुद्धे तु शिष्टास्तत्खण्डमौर्विकाः ॥ ७ ॥

Table 1. Madhava's sine table

Angle A, degrees	R sin A given by Madhava			Modern sin A × (21600 ÷ 2π) to 2 decimals
	In Devanagari script	ISO 15919 transliteration	Decoded angle in minutes' seconds'' thirds'''	
(1)	(2)	(3)	(4)	(5)
3.75	श्रेष्ठं नाम वरिष्ठानां	śreṣṭhaṁ nāma varīṣṭhānām	0224'50''22'''	0224'50''21.83'''
7.5	हिमाद्रिर्वेदभावनः	himādrirvēdabhāvanaḥ	0448'42''58'''	0448'42''57.58'''
11.25	तपनो भानुसूक्तज्ञो	tapanō bhānusūktajñō	0670'40''16'''	0670'40''16.05'''
15	मध्यमं विद्धि दोहनम्	madhyamaṁ viddhi dōhanam	0889'45''15'''	0889'45''15.61'''
18.75	धिगाज्यो नाशानं कष्टं	dhigājyō nāśānaṁ kaṣṭhaṁ	1105'01''39'''	1105'01''38.94'''
22.5	छन्नभोगाशयाम्बिका	channabhōgāśayāmbikā	1315'34''07'''	1315'34''07.44'''
26.25	मृगाहारो नरेशोयं	mṛgāhārō narēśōyaṁ	1520'28''35'''	1520'28''35.46'''
30	वीरो रणजयोत्सुकः	vīrō raṇajayōtsukaḥ	1718'52''24'''	1718'52''24.19'''
33.75	मूलं विशुद्धं नाळस्य	mūlaṁ viśuddhaṁ nāḷasya	1909'54''35'''	1909'54''35.19'''
37.5	गानेषु विरळा नराः	gāneṣu viralā narāḥ	2092'46''03'''	2092'46''03.49'''
41.25	अशुद्धिगुप्ता चोरश्रीः	aśuddhiguptā cōraśrīḥ	2266'39''50'''	2266'39''50.21'''
45	शङ्कुकर्णो नगेश्वरः	śaṅkukarṇō nageśvaraḥ	2430'51''15'''	2430'51''14.59'''
48.75	तनुजो गर्भजो मित्रं	tanujō garbhajō mitraṁ	2584'38''06'''	2584'38''05.53'''
52.5	श्रीमानत्र सुखी सखे	śrīmānatra sukhī sakhē	2727'20''52'''	2727'20''52.38'''
56.25	शशी रात्रौ हिमाहारौ	śāśī rātrou himāhārou	2858'22''55'''	2858'22''55.11'''
60	वेगज्ञः पथि सिन्धुरः	vēgajñāḥ pathi sindhuraḥ	2977'10''34'''	2977'10''33.73'''
63.25	छाया लयो गजो नीलो	chāya layō gajā nīlō	3083'13''17'''	3083'13''16.94'''
67.5	निर्मलो नास्ति सत्कुले	nirmalō nāsti satkulē	3176'03''50'''	3176'03''49.97'''
71.25	रात्रौ दर्पणमभ्राङ्गं	rātrou darpaṇamabhraṅgaṁ	3255'18''22'''	3255'18''21.58'''
75	नागस्तुङ्गनखो बली	nāgastuṅganakhō balī	3320'36''30'''	3320'36''30.20'''
78.75	धीरो युवा कथालोलः	dhīrō yuvā kathālolāḥ	3371'41''29'''	3371'41''29.15'''
82.5	पूज्यो नारीजनैर्भगः	pūjyō nārījanairbhagaḥ	3408'20''11'''	3408'20''10.93'''
86.25	कन्यागारे नागवल्ली	kanyāgārē nāgavallī	3430'23''11'''	3430'23''10.65'''
90	देवो विश्वस्थली भृगुः	devō viśvasthālī bhṛguḥ	3437'44''48'''	3437'44''48.37'''

The 16th-century text *Mahājyānāyana prakāra* cites Madhava as the source for several series derivations for π . In Jyeṣṭhadeva's *Yuktibhāṣā* (c. 1530), written in Malayalam, these series are presented with proofs in terms of the Taylor series expansions for polynomials like $1/(1+x^2)$, with $x = \tan\theta$, etc.



Madhava's Sine Table

Madhava's sine table is a remarkable achievement in trigonometry. The table lists the Rsines (sine multiplied by a radius of approximately 3437.75) of 24 angles from 3.75° to 90° in 3.75° increments. What makes this table particularly fascinating is its encoding method: using the *Katapyadi* system, the mathematical data is represented by letters of the Sanskrit alphabet, giving it the appearance of poetic verses. Although Madhava's original work is lost, the table has been preserved in later texts such as Nilakantha Somayaji's *Aryabhatiyabhashya* and Sankara Variar's commentary on *Tantrasamgraha*. This sine table not only demonstrates the advanced state of mathematics in medieval India but also showcases a unique cultural integration of mathematics with language and literature, making it a significant artifact in the history of mathematics and computational astronomy. The below verse is provided by *Cultural foundations of mathematics* written by C. K. Raju.

Madhava's sine table as shown in Table 1 is organized as follows:

- The first six verses are divided into quarters, each representing one of the 24 angles from 3.75° to 90° , increasing in 3.75° increments.
- These angles are listed in the first column of the table.
- The second column presents the Rsine values, which are encoded using Sanskrit words written in Devanagari script.
- In the third column, these Sanskrit words are transliterated using the ISO 15919 standard.
- The fourth column provides the decoded numerical values, expressed in arcminutes, arcseconds, and archthirds using modern numerals.
- The fifth column shows the modern calculation of these values. This calculation uses the traditional "radius" of $21600 \div 2\pi$, where π is given

to two decimal places in the archthirds. These modern values are provided for comparison with Madhava's original calculations.

Madhava's Important Works

Madhava authored many treatises as given below:

Golavāda (गोलवाद)

Madhyamanayanaprakāra

(मध्यमनयनप्रकार)

Mahājyānāyanaaprakāra (महाज्यनयनप्रकार)
(Method of Computing Great Sines)

Lagnaprakaraṇa (लग्नप्रकरण)

Veṅvāroha (वेण्वारोह)

Sphuṭacandrāpti (स्फुटचन्द्राप्ति)

Aganīta-grahacāra (अगणित-ग्रहचार)

Chandravākyāni (चन्द्रवाक्यानि)

(Table of Moon-mnemonics)

Conclusion

Madhava of Sangamagrama stands as a towering figure in the history of mathematics, whose contributions were far ahead of their time. Despite the mysteries surrounding his life and exact origins, the impact of his work is undeniable and far-reaching. Madhava's ground-breaking discoveries in infinite series, particularly his work on the series for π and trigonometric functions, predated similar European discoveries by centuries. His development of power series expansions for sine, cosine, and arctangent functions laid the groundwork for significant advancements in mathematics and astronomy.

The rediscovery and recognition of Madhava's work in modern times have led to a re-evaluation of the global history of mathematics. It challenges Eurocentric narratives and emphasizes the importance of acknowledging diverse contributions to mathematical knowledge from around the world.

As we continue to uncover and appreciate the depth of his work, Madhava of Sangamagrama's place among the greatest mathematicians in history becomes increasingly secure, inspiring future generations to explore the boundless possibilities of mathematical inquiry.

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