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IIT Madras

Shaastra

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Contents

Volume 01 | Edition 02 | July-August 2021

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On the cover
Telescope dishes in South Africa, which will come under the Square Kilometre Array project, in which India is playing a key part.

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Contents

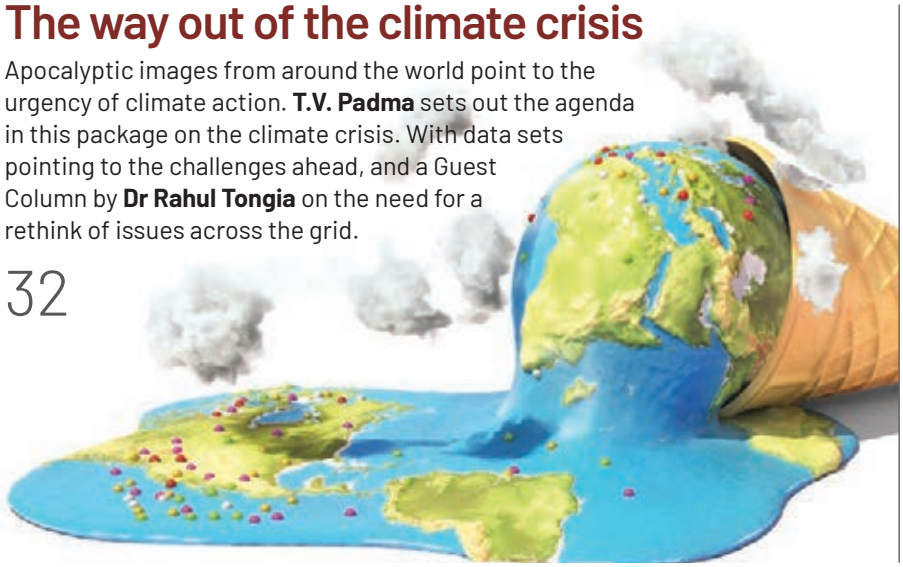
Volume 01 | Edition 02 | July-August 2021

IIT Madras Shaastra

The way out of the climate crisis

Apocalyptic images from around the world point to the urgency of climate action. **T.V. Padma** sets out the agenda in this package on the climate crisis. With data sets pointing to the challenges ahead, and a Guest Column by **Dr Rahul Tongia** on the need for a rethink of issues across the grid.

32



41

In blockchain we trust

Blockchain, the decentralised ledger technology, has the capacity to influence transaction costs by building trust. This trust emerges from the structure of the network itself. Guest Columnist **Niranjan Rajadhyaksha** points us to how this could transform organisations.

Fighting 'fake news' during COVID

42

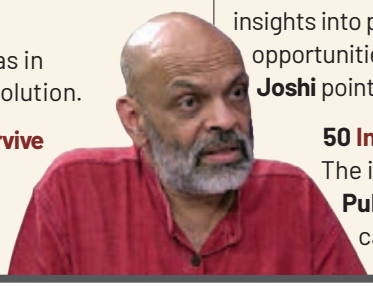
The disinformation epidemic is as virulent as COVID, and just as lethal. But technology can help keep public platforms safe. **Jayadevan P.K.** tells us how social media and technology platforms are fighting back with fact-checks and AI techniques.

52

The future of meat

With lab-cultivated meat, scientists give carnivores something to chew on while also preserving the environment. But can it pass the 'taste test'? **Manupriya** sinks her teeth into a meaty story.

Also...



Letter from the Editor

HARI PULAKKAT

Why big science spends must go on

Spending on big science projects yields substantial benefits, even if only in the long term: these projects generate technology for the future.

This is as good a time as any to look deeply into the significance of all our activities and the rationale for doing them. In troubled times, people tend to focus on the truly important and meaningful, leaving other activities to more sanguine periods when we have plenty of time and money. This is as true of corporations and governments as of individuals. At a time of serious financial crunch, what are the activities that the government should support? In science, which is the purview of this magazine, what kind of research is worthy of funding?

This is an old question and will be asked again and again throughout this century, and probably in the next century as well. However, at a time when COVID-19 has depleted government coffers, the public has a right to ask whether expensive blue-sky research should be funded. Of what use is high energy physics or cosmology or astronomy to the public? A state-of-the-art telescope can cost a billion dollars. Setting up a particle accelerator will cost several times as much. The running cost of a large accelerator can be a billion dollars a year.

This is why even rich countries are collaborating to do big science. Although collaboration can bring down the cost of the project for each country, it is still expensive for the participants. Should a middle-income country like India spend substantial money to participate in a big science project? India is now participating in six multi-billion-dollar science projects, each costing the country more than ₹1,000 crore, apart from working on one of its own. What will the taxpayers get in return from them? It is not an easy question to answer, and our cover story is about the possible answers.

Pallab Roygupta talks to scientists in several laboratories and private companies to investigate the benefits of big science, both intellectual and commercial. As he reports, the benefits are not easy to pin down in the short term but substantial in the long term, as big science projects generate technology for the future. For private companies, exposure to technology early in their development can mean a good high-tech business a decade or two later.

On page 18, Gauri Kamath reports on the possibilities of point-of-care diagnostics. In a country with a substantial rural population, often in places far away from cities and towns, centralised testing can delay the diagnosis of serious diseases. However, as she says in her story, "conventional technologies were not designed for rapid turnaround or distributed deployment." Newer technologies promise to change this situation and help cure or better manage serious diseases through early detection.

On other pages, we also look at India's options in tackling climate change, the improving science behind weather forecasting, the success of the KIIT business incubator in Bhubaneswar, and the lure of lab meat. Rapid climate change is the defining problem of this century, and the world is not responding rapidly enough. We have a set of stories and graphics on the problem. T.V. Padma gives the background for the IPCC Report and the Conference of the Parties in November; the graphics on pages 32 to 34 capture India's path so far and the possible future in renewable energy; our guest columnist Rahul Tongia writes how India should reassess its options in pricing, regulation and innovation.

As the earth warms up, and the weather becomes unpredictable, it becomes more and more important to predict it accurately. India has invested, through the monsoon mission, heavily on weather forecasting. The country has high-performance computers and an improved network for collecting data. However, the science that drives weather is not understood very well. On page 38, Mywish Anand writes about how the Indian Institute of Tropical Meteorology in Pune is making progress in this regard.

On page 14, Tazeen Qureshy writes about the rise of the KIIT business incubator, despite being located in a Tier-II city that did not have a good business ecosystem in its early days. The KIIT business incubator has now given birth to 230 companies, one of which is on the verge of becoming a unicorn. And, unlike other smaller towns, it is generating start-ups in high-technology areas. The future of technology start-ups is not just in the cosmopolitan cities.

Finally, on page 60, Dilip D'Souza writes about the physicist Steven Weinberg who passed away on July 23. He was not just another Nobel Prize winner. One of his papers, just three pages long, changed the way physics is practised. •

Letters to the Editor

I was delighted to flip through the pages of the inaugural issue of Shaastra. *It's a wonderful initiative.*

PROF B.S. MURTY
Director, IIT Hyderabad

Such a magazine was needed, and that need has now been fulfilled.

J.S. BHAT
Director, IIIT Surat

This magazine will go a long way in making India an innovation hub.

RAJENDRA RATNOO
Joint Secretary and Controller General of IPRs (PDTMs)

As an Alumnus of IIT Madras, a telecom engineer, and a scientist at Bell Labs, I thoroughly enjoyed reading the magazine. Extremely well done.

DR C.S. RAO
Chairman and Co-Founder, QuadGen Wireless Solutions Pvt Ltd

The articles in the inaugural issue of *Shaastra* are very topical and interesting. It's a great initiative.

K. LAKSHMI PRASAD
Principal, B.V. Raju Institute of Technology

The inaugural issue of Shaastra *was excellent. Among the several interesting articles, I was particularly pleased to see the Guest Column by Guru Madhavan.*

DEV MANI
Former Associate Executive Director of the National Academy of Sciences in the Office of US National Research Council

Sincere and hearty thanks to the *Shaastra* team.

NIRANJAN MADHUSOODHAN

Shaastra offers the very best Science and Technology content. It is particularly useful for me as a UPSC aspirant.

RAUNAK JAISWAL

Looks like a world-class journal.

NAREN RAGOTHAMAN

Shaastra is amazing: it gave me goosebumps. Happy to see such an initiative from IITM, from where I graduated in 2020.

BHUPESH MARKAM

Excellent maiden effort.

S. KRISHNAKUMAR
(Class of 1977)

Congratulations on bringing out such a nice magazine. For the benefit of ebook readers, can you also provide the magazine in an ebook format like .mobi or .epub? Converting the pdf file to .epub entails loss of formating.

ADIL MOHAMMED K

We will certainly consider it, going forward. EDITOR

Congratulations to those driving the *Shaastra* project. I appreciate the depth of the contents, and I look forward to more such rich content. One small suggestion: I read the magazine on my smartphone. Can you make it possible for me to go directly to an article of my interest from the Contents page?

VICTOR C PAUL

Thanks for the suggestion. We will take this on board. EDITOR

TWITTER CHATTER

Best wishes to @IITMadras for the launch of *Shaastra*, first-of-its-kind science and technology magazine in India. It will inspire our youth to innovate and find solutions to people's problems scientifically!

SANJAY DHOTRE
Minister of State for Education, Communications, Electronics & IT, Government of India

An amazing initiative... It will advance science communication and inspire students to get involved in research work.

R.K. SHARMA

Great initiative. (Was) looking for something of this sort.

RAM

This is awesome!

KRITHIKA SIVASWAMY

An interesting science magazine. Great quality articles.

N. DAYASINDHU

Great initiative. Congratulations.

PRASHANT M. NIJASURE

The Cover Story on COVID-related research and development was an eye-opener. While it helps to see how tough it is, it is also encouraging to see Indians working to breach frontiers. I hope Mynvax will succeed.

UDAYA KUMAR P.L.

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An AI model that can identify cancer-causing gene mutation

A team of researchers at the Indian Institute of Technology Madras (IITM) has developed an artificial intelligence-based mathematical model capable of identifying cancer-causing 'driver mutations' in cells.

Identifying driver mutations, which are responsible for disease progression, is the key to accelerating early diagnosis as well as developing personalised therapies.

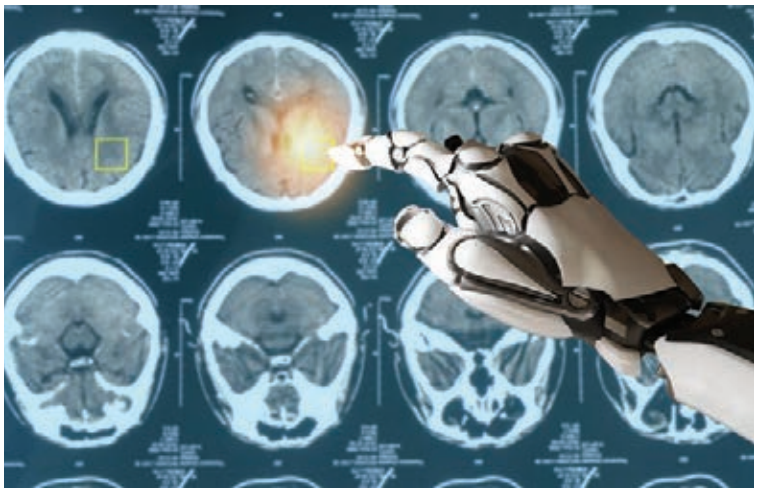

PHOTO: SHUTTERSTOCK

The algorithm perfected by a team led by Prof B. Ravindran, head of IITM's Robert Bosch Centre for Data Science and AI (RBCDSAI), and Dr Karthik Raman, an RBCDSAI faculty and Coordinator of the Centre for Integrative Biology and Systems medicinE (IBSE) at IITM, can help predict the driver mutations pretty accurately.

Cancer is caused by the accumulation of somatic mutations – genetic alterations acquired by a cell, which are passed on to the progeny of the mutated cell in the course of cell division. Such mutations are frequently caused by environmental factors such as exposure to ultraviolet radiation or to certain chemicals. A few of these mutations are responsible for the disease progression and are therefore called driver mutations. Other mutations are functionally neutral and have no role in the disease progression. These are called passenger mutations.

"One of the major challenges faced by cancer researchers involves the differentiation between the relatively small number of 'driver' mutations that enable the cancer cells to grow and the large number of 'passenger' mutations that do not have any effect on the progression of the disease," said Ravindran, also Mindtree Faculty Fellow at IIT Madras.

Identifying driver mutations, which are responsible for cancer progression, is the key to accelerating early diagnosis.

"Detecting driver mutations, particularly rare ones, is an exceptionally difficult task," said Raman, also associate professor in the Department of Biotechnology, Bhupat and Jyoti Mehta School of Biosciences, at IIT Madras.

In the study, which appeared recently in the journal *Cancers*, the researchers approached the problem rather innovatively.

Their goal was to discover patterns in the DNA sequences – made up of four letters, or bases, A, T, G and C surrounding a particular site of alteration. The underlying hypothesis was that these patterns would be unique to individual types of mutations – drivers and passengers — and could therefore be modelled mathematically to distinguish between the two classes. Using sophisticated AI techniques, the researchers developed NBDriver, a novel prediction algorithm, and tested its performance on several open-source cancer mutation datasets.

They showed that their model could distinguish between driver and passenger mutations from cancer genes with an accuracy of 89%; that could be improved to 95% if predictions from NBDriver are combined with those from three commonly used driver prediction algorithms.

Next, the team plans to develop an easy-to-use web interface that will enable cancer researchers to get predictions on their preferred set of variants as well as carry out further studies on the context of these mutations and how they impact the evolution of cancer. •

Hard materials that mend themselves

It is a truth universally acknowledged that accidentally dropped handphones lead not only to shattered phone screens but also to broken hearts. And given that phones get dropped more often than we like, many among us may have wished for a screen that miraculously mends itself.

Well, that wish is close to being granted, thanks to the pioneering work by a team of Indian scientists.

Researchers from the Indian Institute of Science Education and Research Kolkata (IISER-K) and their collaborators from the Indian Institute of Technology Kharagpur (IITKGP) have synthesised an organic crystalline material that has the ability to spontaneously repair itself within a fraction of a second when it is broken.

Devices that we use daily often break down due to mechanical damage, and have to be repaired or replaced. This shortens the life of the equipment and increases maintenance costs. In some cases, human intervention for restoration is not possible.

Materials scientists have been in search of such smart materials that can self-repair as they have huge application potential in industries ranging from electronics to aero-

Continued on *page 8*

PHOTO: SHUTTERSTOCK

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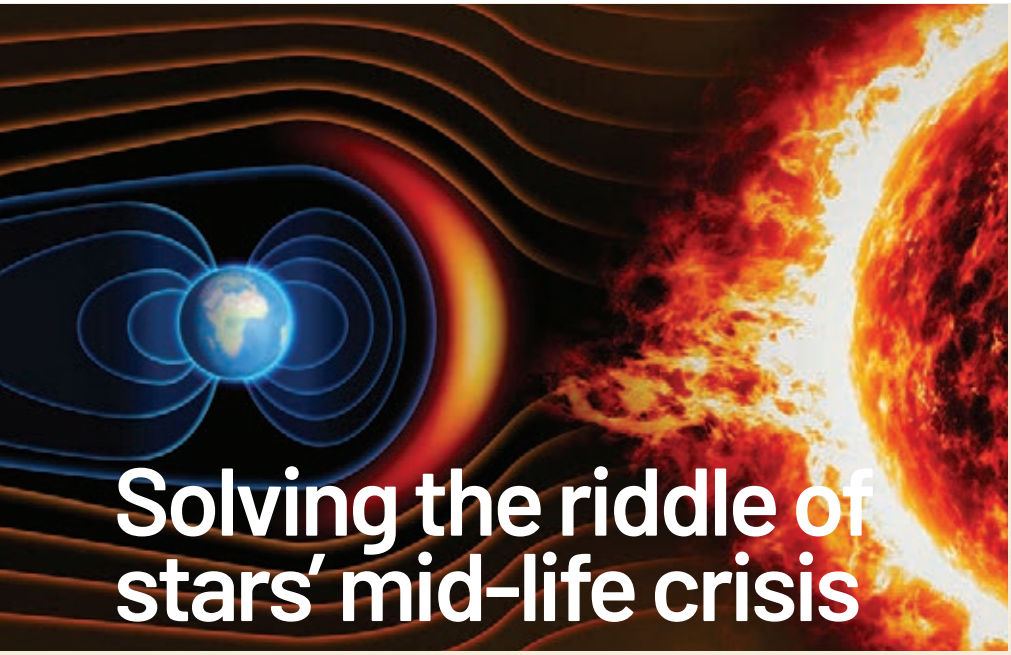

Solving the riddle of stars' mid-life crisis

PHOTO: SHUTTERSTOCK

Researchers from the Indian Institute of Science Education and Research (IISER) in Kolkata seem to have resolved a riddle that confused astrophysicists studying Sun-like stars that have crossed the middle age of their existence.

The theoretical understanding put forward by a team led by Prof Dibyendu Nandi, professor at IISER's Centre of Excellence in Space Sciences India, would help explain why middle-aged stars experience an unexplained breakdown in established techniques for measuring their age, and why solar-like stars transition into a magnetically inactive phase as they age. The study, which appeared recently in the *Monthly Notices of the Royal Astronomical Society: Letters* journal, had contributions from Bindesh Tripathi and Prof Soumitro Banerjee, both from IISER Kolkata.

A star is continuously giving away a steady stream of plasma, called stellar wind, which is moving away from the star. In the case of the Sun, it is called solar wind. That happens because the outer part of the corona (atmosphere) is hot. Because it is hot, it expands out, facilitating this plasma flow. The stellar wind is modulated by the magnetic field. "If the star has more magnetic output, the corona tends to be more active and hotter. This will help it expand more. So, the wind is faster if a star has a stronger magnetic field," says Nandi.

This steady drain of charged particles results in the star losing its angular momentum. Angular momentum to a spinning object is quite similar to velocity to an object moving in a linear fashion.

The loss of angular momentum leads to stars slowing down over billions of years. But this decrease in activity and the rotation rate over time is expected to be smooth and predictable. As this slowdown is linked to the magnetic field on the outer surface of the star, it is called magnetic braking. Magnetic braking gave astronomers a tool called "stellar gyrochronology" to measure the age of stars for nearly two decades.

The more magnetic field there is, the stronger the stellar wind, and the greater the loss of angular momentum; this leads to a faster slowdown of the star, the IISER professor explains.

However, it was recently noticed that "magnetic braking fails after stars reach their mid-life, but the reason was not known. This paper explains why," says Nandi.

Using dynamo models of magnetic field generation in stars, the team showed that at about the age of the Sun, the magnetic field generation mechanism of stars suddenly becomes sub-critical or less efficient. This allows stars to exist in two distinct activity states: a low-activity phase and an active phase. A middle-aged star like the Sun can often switch to the low-activity phase, resulting in drastically reduced angular momentum losses, as recently observed by some researchers, Nandi said.

The study explains why middle-aged stars experience a breakdown in established techniques for measuring their age.

This insight is significant because stellar gyrochronology is considered to be an efficient method to gauge the age of stars. Ascertaining the age of the Sun is not difficult because the dating of meteorites can give clues to it. But that is not the case with far-away stars, observes Nandi. •

Continued from *page 6*

space. Some have been successful in incorporating this ability to autonomously restore shape or self-heal in certain metals and polymers.

But IISER Kolkata and IIT Kharagpur scientists have achieved something unique. Up until now, this self-healing property has been achieved only in materials that are soft and amorphous. And they require some external stimulus such as heat, light or a chemical agent in order to trigger the healing process. The material that the Indian researchers synthesised, on the other hand, has a crystalline structure and is 10 times harder than other smart materials; for that reason, it may find use in most electronics and optical applications.

The coupling of self-healing properties with crystallinity could enable a number of long-sought technologies. For instance, many micro-electronic devices whose function is based on precision positioning require accurately oriented, highly crystalline piezoelectric crystals. Piezoelectric crystals are a class of materials that generate electricity when they undergo a mechanical impact. Such piezoelectric materials must withstand prolonged mechanical loading and unloading cycles; hence, fracture-healing ability is critical to boost their durability. Some such devices are high-end micro-chips, high-precision mechanical sensors, actuators, and micro-robotic devices.

When crystals are fractured, they develop charged surfaces that attract each other, drawing the two faces together to enable self-repair.

The ability to autonomously restore shape or self-heal is a useful property that has been incorporated into a range of materials, including metals and polymers. The Indian team led by C. Malla Reddy, a chemistry professor at IISER, and Nirmalya Ghosh, his colleague from the Physical Sciences Department, managed to do this in piezoelectric molecular crystals.

In their paper published in *Science* journal in July, the scientists showed that when crystals are fractured, they develop charged surfaces that attract each other, drawing the two faces together to enable self-repair as long they remain within a critical distance of each other.

The crystals created by Reddy and his colleagues were needle-shaped. The scientists hope that further research into such materials may eventually lead to the development of smart gadgets that self-repair cracks or scratches. •

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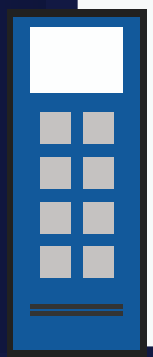

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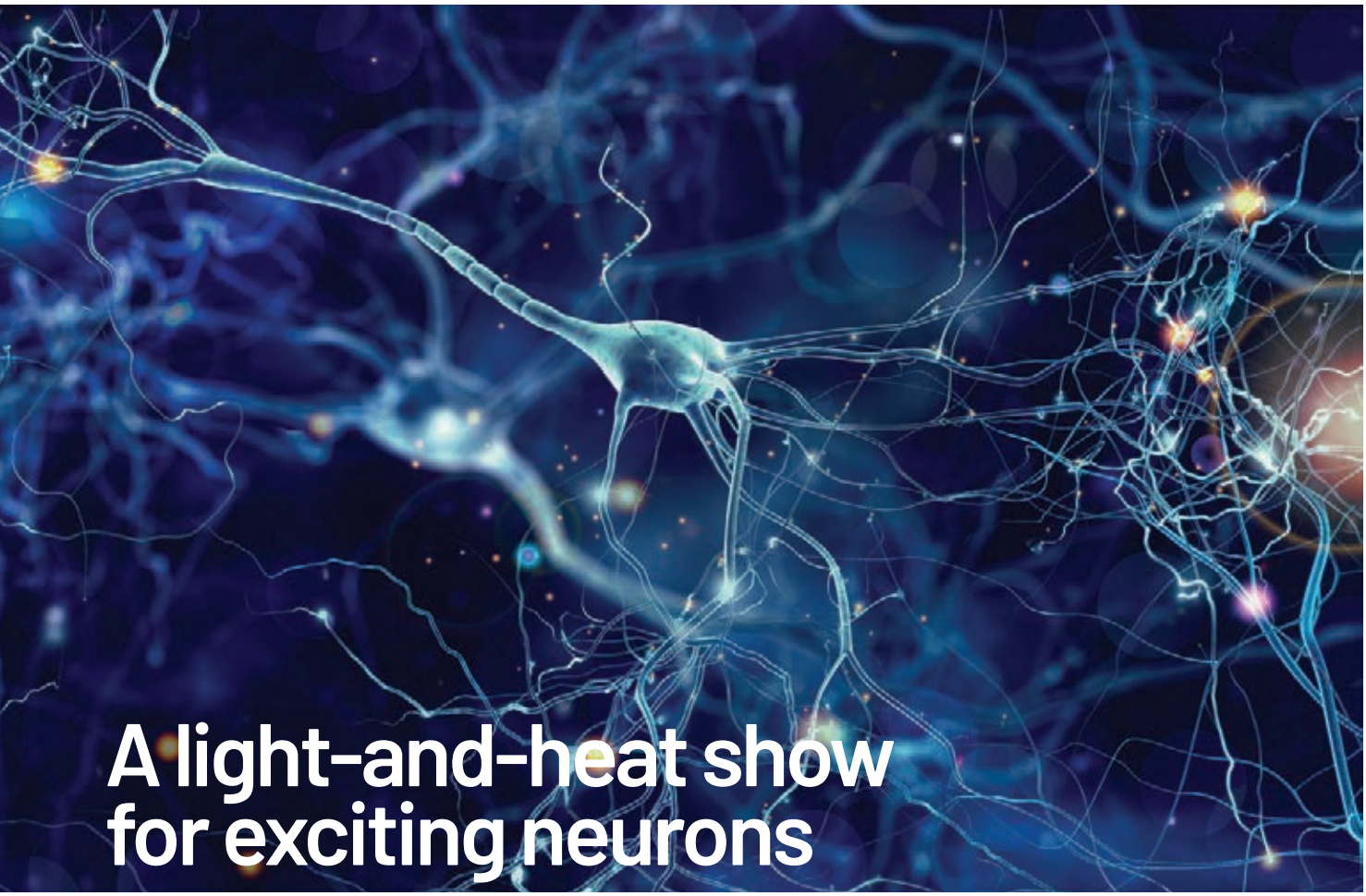

A light-and-heat show for exciting neurons

PHOTO: SHUTTERSTOCK

In what could be an innovative use of nanomaterials in biomedical application, a team of India-born scientists in Washington University (WU) in St. Louis, has used nanoparticles as heaters to manipulate the electrical activity of neurons in the brain as well as heart muscles cells.

Srikanth Singamaneni, a materials scientist, and Barani Raman, a biomedical engineer, and their teams at McKelvey School of Engineering at WU collaborated to develop a non-invasive technology that inhibits the electrical activity of neurons using polydopamine (PDA) nanoparticles and near-infrared light. The negatively charged PDA nanoparticles, which selectively bind to neurons, absorb near-infrared light that creates heat, which is then transferred to the neurons, inhibiting their electrical activity.

"We showed we can inhibit the activity of these neurons and stop their firing, not just on and off, but in a graded manner," said Singamaneni, a professor in the Department of Mechanical Engineering & Materials Science. "By controlling the light intensity, we can control the electrical activity of the neurons. Once we stopped the light, we can completely bring them back again without any damage," he said, of their work published in *Advanced Materials* journal in July.

In addition to their ability to efficiently convert light into heat, the PDA nanoparticles are highly biocompatible and biodegradable. The nanoparticles eventually degrade, making them a convenient tool for use in *in vitro* and *in vivo* experiments in the future.

"When you pour cream into hot coffee, it dissolves and becomes creamed coffee through the process of diffusion," Singamaneni explained. "It is similar to the process that controls which ions flow in and out of the neurons." Diffusion, he notes, depends on temperature, "so if you have a good handle on the heat, you control the rate of diffusion close to the neurons. This would in turn impact the electrical activity of the cell. This study demonstrates the concept that the photothermal effect, converting light into heat, near the vicinity of nanoparticles-tagged neurons can be used as a way to control specific neurons remotely."

Scientists have now developed a non-invasive technology that inhibits the electrical activity of neurons using polydopamine nanoparticles and near-infrared light.

The team also designed a photothermal foam that is similar to a sugar cube, forming a dense population of nanoparticles in tight packaging that acts more quickly than individual sugar crystals that disperse, Raman said.

"With so many of them packed in a small volume, the foam is quicker in transducing light to heat and give more efficient control to only the neurons we want," he said. "You don't have to use high-intensity power to generate the same effect."

In addition, the team, which included Jon Silva, associate professor of biomedical engineering, applied the PDA nanoparticles to cardiomyocytes, or heart muscle cells. Interestingly, the photothermal process excited the cardiomyocytes, showing that the process can increase or decrease the excitability in cells depending on their type.

"The excitability of a cell or tissue, whether it be cardiomyocytes or muscle cells, depends to a certain extent on diffusion," Raman said. "While cardiomyocytes have a different set of rules, the principle that controls the sensitivity to temperature can be expected to be similar."

Now, the team is looking at how different types of neurons respond to the stimulation process. They will be targeting particular neurons by selectively binding the nanoparticles to provide more selective control. •

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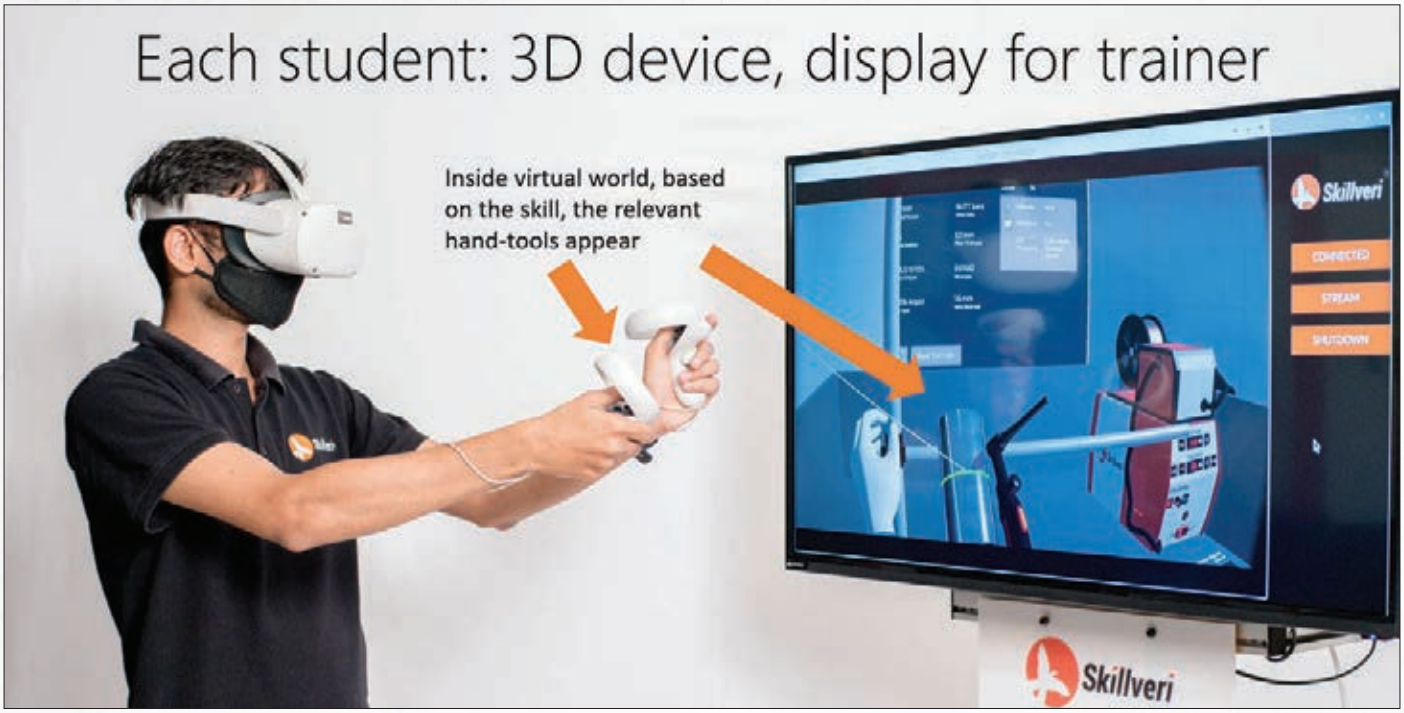

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Start-up stars

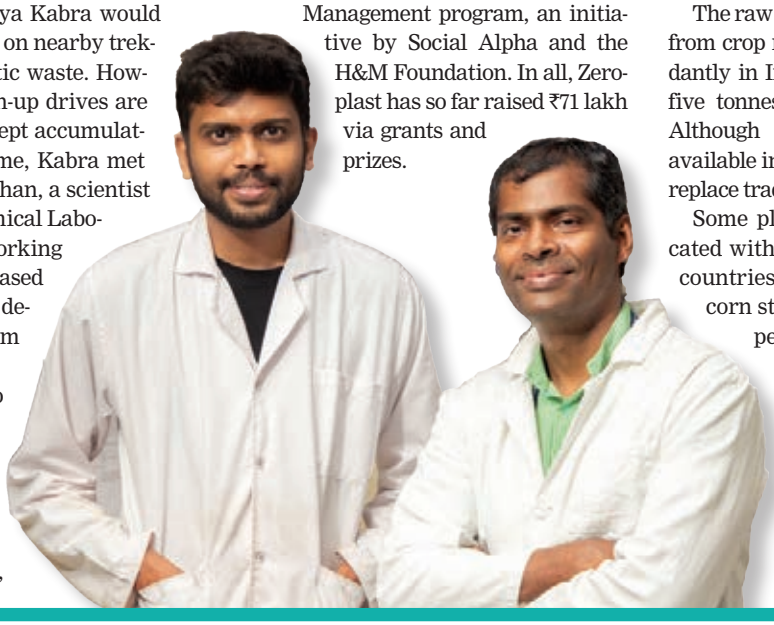
Profiles of three entrepreneurial ideas in various stages of evolution.

Zeroplast

Founders: **Aditya Kabra, Kadhiravan Shanmuganathan**
Year: **2019**
Big idea: **Bioplastics from crop residue**

As a Master's student at the Indian Institute of Science Education and Research Pune, Aditya Kabra would often go on clean-up drives on nearby trekking trails to remove plastic waste. However, he realised that clean-up drives are a temporary fix: plastics kept accumulating quickly. About this time, Kabra met Kadhiravan Shanmuganathan, a scientist at the CSIR- National Chemical Laboratory in Pune, who was working on developing cellulose-based plastic alternatives. They decided to join forces and form Zeroplast in 2019.

Zeroplast aims to kill two birds at one stroke: collect crop residue that farmers discard, and use it to make durable bioplastics. This way, farmers will burn less crop residue, and non-biodegradable waste generation will be reduced. The company got going with a NIDHI-PRAYAS grant from the Department of Science and Technology in 2019. In 2020, it received the Biotechnology Ignition Grant from the Department of Biotechnology (DBT). And in 2021, it was among the top 5 start-ups in Techtonic–Innovations in Waste Management program, an initiative by Social Alpha and the H&M Foundation. In all, Zeroplast has so far raised ₹71 lakh via grants and prizes.



The raw material for Zeroplast is cellulose from crop residue, which is available abundantly in India. "A two-acre farm produces five tonnes of crop residue," says Kabra. Although bioplastic-based products are available in India, they have not been able to replace traditional fossil-fuel-based plastics.

Some plastics made in India are fabricated with bioplastics sourced from other countries. Another category, made with corn starch, is quite popular, but is expensive. A few start-ups are making bioplastics using bacteria and even seaweeds.

To make their bioplastic, the Zeroplast team extracts cellulose from crop residue, using the same technology that the paper industry uses. It then converts the cellulose into bioplas-

Myelin Foundry

Founders: **Gopichand Katragadda**
Year: **2019**
Big idea: **Smart devices that perform computation at site**

Gopichand Katragadda had worked with Artificial Intelligence and neural networks since the early 1990s and knew about its limitations to solve industrial problems. When he sensed real advances in the field a few years ago, he knew it was time to bite the bullet with a start-up.

The change that Katragadda wanted to exploit came in neural networks, and specifically in convolution neural networks. Till recently, as high-performance computation was not easily available, the field applications were limited to simple use cases. Computing at site was difficult, and so it was not possible to perform real-time applications. Over the past decade, breakthroughs in convolution neural networks along with other advances changed. Katragadda quit his job as Group CTO of Tata Sons and set up Myelin Foundry in January 2019.

Computation at site is a necessary condition for taking real-time decisions. Cold rolling of metal sheets requires precise adjustment of temperature and pressure in real time. Driver assistance systems need to analyse data instantly and provide constant inputs to the driver. Over-the-top (OTT) media platforms require constant data analysis to understand what people are watching. Personal medical devices need to monitor data all the time to avoid emergencies.

In all these cases, data were being sent regularly to the cloud for analysis. Edge computing, a paradigm where the processing and storage of data is done close to where data is generated, wasn't being done in most of the cases. There were reasons for that. The data being generated were complex, and it wasn't easy to process them in limited computing environments consuming small amounts of energy. In some cases, like mobile phones, the edge was different in each case. There was no standard hardware, which in many cases was using old-generation technology as well. From 2017 onwards, the amount

tic through a series of proprietary steps. The end-product is a bioplastic that does not have a long manufacturing process, is thermostable, biodegradable, and matches the performance of traditional plastics.

Zeroplast is currently working on two categories of bioplastics: a flexible type that can be used as thin films used in packaging and disposable cutlery, and a rigid type for use in toys, packaging for cosmetics. Zeroplast has obtained certification from the Indian Institute of Packaging for using its bioplastic in food packaging. In fact, Zeroplast bioplastic's food safety performance is better than conventional plastic as it does not leach out chemicals, says Kabra. Its barrier properties—the ability to act as an effective barrier against water and oil—are comparable to regular plastics and it is stable at up to 140°C. It is also easily compostable in natural conditions. Many traditional bioplastics require high temperature industrial composting facilities, but a Zeroplast-produced 200-GSM bioplastic can degrade up to 96% in 45 days in a home composting unit, the company claims. Even in natural soil environments, the bioplastic decomposes readily. In other words, if a Zeroplast bioplastic is thrown in the open, it will decompose into organic matter within 60 days.

Zeroplast needs to take its product out of the lab into an industrial facility. If it can validate its technology at scale and make a cost-efficient product, in a few years you might be drinking tea in a compostable bioplastic cup from Zeroplast. •

— **Manupriya**

of hardware with advanced capabilities began to increase rapidly. Companies developed techniques using AI to simplify problems. Recently, techniques in convolution neural networks became powerful enough to identify images well. Myelin Foundry, which has raised $2.5 million, is setting out to exploit these advances.

Myelin's initial business model was to provide microservices (as the company calls it) along with a product. A product sits on the consumer's hardware, analyses information and provides feedback for rapid action. It allows a boiler, for example, to be maintained before it fails completely. Another project was to use heart rate variability and bioimpedance, which is the response of the body to an electric current, to predict inflammation in the body.

Such services may become common in the future, as devices acquire intelligence over a period of time. At the moment, Myelin has two customers in OTT platforms, five industrial pilot projects and two paying customers. •

— **Hari Pulakkat**

Planys Technologies

Founders: **Tanuj Jhunjhunwala, Vineet Upadhyay, Rakesh Sirikonda, Prabhu Rajagopal, Krishnan Balasubramanian**
Year: **2015**
Big idea: **Underwater robots**

As a B. Tech student at the Indian Institute of Technology Madras (IITM) Department of Mechanical Engineering, Tanuj Jhunjhunwala was no stranger to underwater robots. Along with his friends Vineet Upadhyay and Rakesh Sirikonda, he had built many robots at the department's tinkering lab, which could function underwater. The trio was also aware of the IITM faculty's work in advising ports and dams in the maintenance and safekeeping of underwater structures. By the time they graduated, it became apparent to the three that a significant opportunity lay in monitoring the health of underwater structures – and that given their experience in building underwater robots, they could fill this need gap.

In June 2015, Jhunjhunwala, Upadhyay, and Sirikonda, along with two IITM faculty members—Prabhu Rajagopal and Krishnan Balasubramanian—started Planys Technologies. The idea of using marine robots to monitor the health of underwater structures was new in India. Until then, underwater monitoring was done by divers who would visually inspect structures and report on their health. This method has many drawbacks: hazardous conditions for divers, inaccurate post-inspection data analysis, non-digital reporting, and human limitations.

Planys' robots collect data through three methods: visual inspection, measuring the level of corrosion, and using sonar sensors to assess underwater conditions. The robots are equipped to conduct high-definition marine videography, murky-water inspection and robotic cleaning. The use of ultrasonic, magnetic, and sonar sensors provide unique insights.

For example, while inspecting a reservoir, Planys robots discovered high silt deposition at the base, which compromised the reservoir's holding capacity.

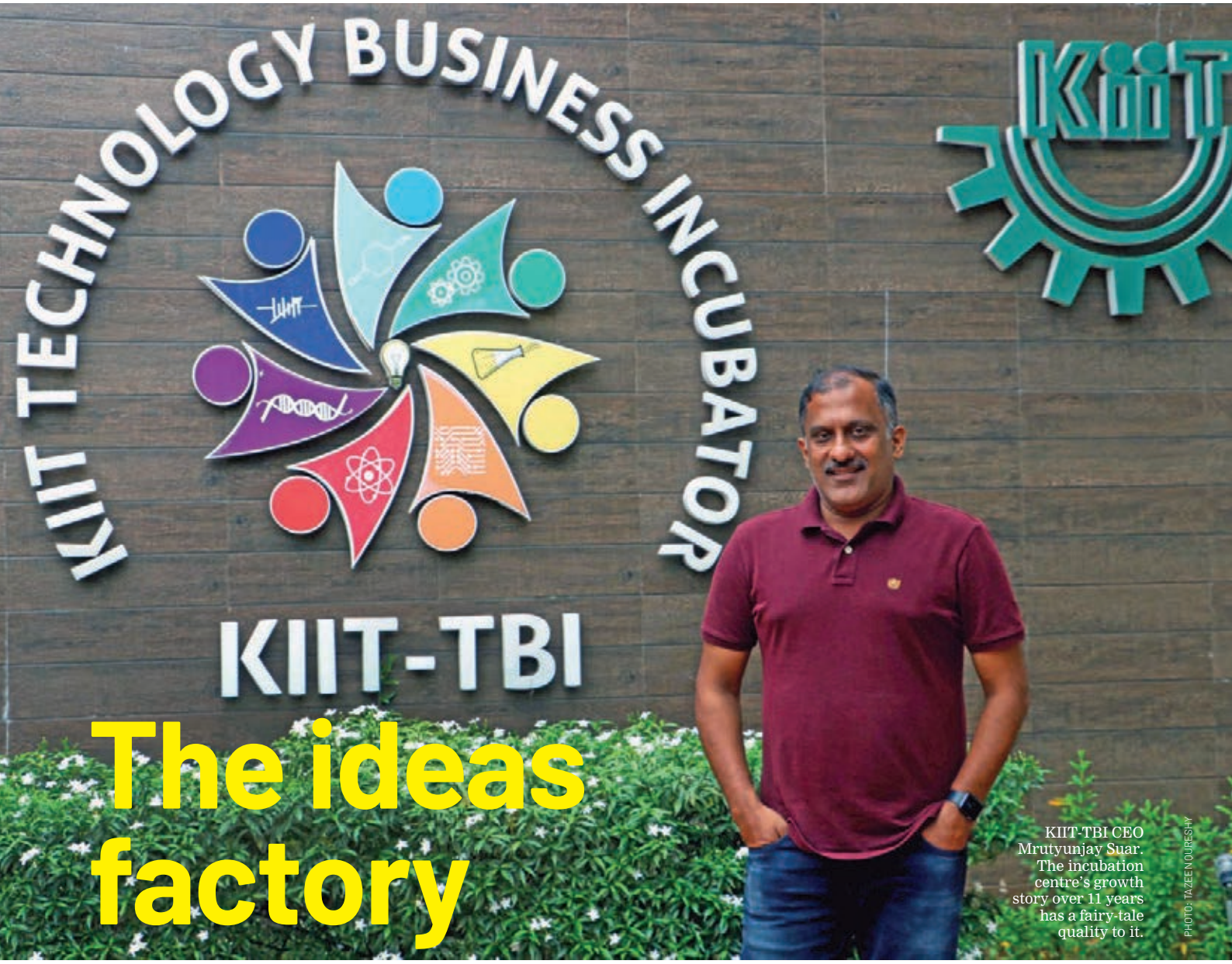
Planys also innovated in the way information is made available to clients, with digital dashboards allowing assessment of hours' worth of data rapidly and comparison of data across years. Companies with underwater structures can use the information to shift from a time-centric protocol to a risk-centric protocol to manage the asset. Planys' USP is that it provides an end-to-end underwater inspection solution: use of robots, non-destructive testing of structures, and digital reporting.

Planys' robots are being used by the water resources department of States (Karnataka, Maharashtra); the Indian Railways; PSUs, including NTPC, HPCL and BPCL; highways departments; EPC contractors like L&T; and the Chennai port.

Planys currently works on a service-based model. Jhunjhunwala likens it to a taxi service: the Planys team bring the robots to underwater structures whenever an inspection is needed.

Planys is also eyeing the international market. As Planys looks to expand its footprint, its biggest challenge is in convincing customers to transition from traditional methods to technology-enabled methods of underwater asset management. •

— **Manupriya**



The ideas factory

KIIT-TBI CEO Mrutyunjay Suar. The incubation centre's growth story over 11 years has a fairy-tale quality to it.

PHOTO: TAZEEN QURESHY

The KIIT Technology Business Incubator in Bhubaneswar punches above its weight in churning out successful start-ups. What's its secret sauce?

TAZEEN QURESHY

On a good day, the view from the top floor of the School of Biotechnology at the Kalinga Institute of Industrial Technology (KIIT) in Bhubaneswar can be enchanting. The campus of the Deemed University, which was recognised in 2020 as an Institute of Eminence, is set in a verdant part of Odisha's capital. Away to the east, even if out of vision range, the Kuakhai, a tributary of the Mahanadi, flows serenely; and to the north are the Nandankanan Zoological Park, the world's only conservation breeding centre of Indian pangolins, and the picturesque Kanjia Lake.

Gazing out from that top floor, back in 2009, Prof Mrutyunjay Suar perhaps saw a bit farther out than most. What he saw was the future of the Centre for Innovation and Entrepreneurship, housed in that top floor, which he had conceived as an incubation centre where business ideas would be birthed, nursed and sent out into the world. And that future, to him, seemed golden – even given the challenges of getting students enthused about such ideas as innovation and entrepreneurship and (gasp!) risk in a State where a salaried job was perceived as the overarching career aspiration.

In Odisha, jobs used to be seen as offering stability, says Suar, now CEO of what has evolved to become the KIIT Technology Business Incubator (KIIT-TBI). And to get students to understand that they could become job creators instead of job seekers was "like teaching them a new language from scratch," he recalls.

Today, KIIT-TBI, which operates out of its own 1.3-lakh-square-feet campus, is acknowledged as the engine that drives the State's start-up ecosystem. Many of the 230 start-ups incubated here have acquitted themselves with distinction in their respective business fields; at least one is on the threshold of becoming a unicorn.

In many ways, the story of how KIIT-TBI came to be in a Tier-II city, and of how it has spread its wings in just 11 years, has a fairy-tale quality to it. That it traces its roots to a private university in a State that, back then, did not have a start-up policy, nor any enabling factors like access to funding, a network of investors, a culture of innovation or expertise makes

this even more striking. Parallels with Silicon Valley are, of course, exaggerated, but to the extent that there are echoes of companies that started off in a garage and went on to become giants, there certainly are some shared experiences.

Of course, Bhubaneswar had some things going for it: even back in 2009, it was acknowledged as a centre for higher education, with several universities, both government-run and privately funded. Over in California, Stanford University and other state colleges played a crucial role in the development of Silicon Valley; in Bhubaneswar, it was a private university, KIIT, that became a feeder for innovators.

THE BEGINNINGS

The KIIT incubation centre was conceptualised in 2008 as the Centre for Innovation and Entrepreneurship, and after securing sanction and funding from the Department of Science and Technology (DST), it became KIIT-TBI. The 'start-up team' at TBI was composed mostly of academic staff of the School of Biotechnology of KIIT University. Over time, that core group went about identifying and establishing a network of mentors and investors.

These mentors were not desk-bound academic professors who had only a lot of textbook wisdom to impart. These were enterprising people who could ideate, connect and help build an innovation ecosystem. The first generation of innovators were predominantly students, given the ease of tapping their potential and working closely with them.

One of the early success stories was FarEye, a digital logistics start-up conceived by three KIIT graduates Kushal Nahata, Gautam Kumar and Gaurav Srivastava, and incubated at KIIT-TBI. Today it has a client base of over 150, including global logistics firms, retail giants, and health and home-care products companies, across 30 countries. After raising $100 million in Series E round funding in May 2021, the company has set its sights on becoming a unicorn, perhaps as early as this fiscal year.

Also among the early start-ups that traces its roots to KIIT-TBI is Maa Kanak Biofertilizers, which sought (and secured) expertise on technology to scale up production and market its produce.

Success of this sort begat yet more success. The high-water mark set by these first-generation start-ups attracted more innovators, and soon KIIT-TBI was humming with entrepreneurial energy.

THE SECRET SAUCE

Although Bhubaneswar acquired an innovation ecosystem much later than, say, Kolkata and Indore, it is KIIT-TBI's somewhat unique model that gives it a sustainable edge. Unlike other incubation centres, which provide infrastructure support and co-working spaces, KIIT-TBI focusses on deep technology and high-risk innovations with game-changing potential. The centre does, of course, promote technology, biotech and social incubation enterprises, but almost 75% of its incubatees operate in the manufacturing sector.

"Our USP is manufacturing and high-tech innovations," says Suar. "We always wanted to go beyond the IT sector. We want to spur innovations that will impact human life."

This sharp focus has helped KIIT-TBI stand out, and it shows in the profiles of the companies it has nurtured. Whereas in Indore, the top start-ups from similar incubation centres operate in the realms of food delivery, web and app development or computer software, KIIT-TBI is into deep tech and manufacturing.

PHOTO: BY SPECIAL ARRANGEMENT

Dr Nusrat Sanghamitra started up biotech company CyGenica with research grants secured by KIIT-TBI.

Nusrat Sanghamitra's CyGenica recently raised $1.4 million in a seed fund investment round led by Irish venture capital investor SOSV.

The experience of Dr Nusrat Sanghamitra, who co-founded CyGenica, a biotech company that uses technology for safe therapeutics delivery systems, is illustrative.

In 2016, Sanghamitra, then a researcher, was looking for funding, and chanced upon a KIIT-TBI advertisement. "I had no idea about the incubation centre," she says. "I wanted funding for my research and approached KIIT-TBI. They helped me secure several grants, including a grant of ₹50 lakh from BIRAC" (Biotechnology Industry Research Assistance Council, the not-for-profit public sector enterprise from the Department of Biotechnology). Once her work became more widely known, "there was no dearth of funding," she adds.

CyGenica, now an Indo-Irish company based out of Pune and Cork, has an ongoing collaboration with University College Cork, one of Ireland's top universities. The company has developed technology that uses the drilling technique to precisely inject molecules to specific cancer-affected cells, reducing the risk of side-effects and cost of treatment. It recently raised $1.4 million in a seed fund investment round led by Irish venture capital investor SOSV.

The KIIT University ecosystem, of which KIIT-TBI is an intrinsic part, has helped start-ups in non-traditional ways, too – for instance by delivering a ready market for a food manufacturing start-up. Rahul Chatterjee, a student innovator at KIIT-TBI, conceived of his start-up, Krea Foods, even when was in his third year at the School of Biotechnology. Krea Foods manufactures millet-based bakery and confectionary products, which are a healthful substitute for carbohydrates.

The University campus, with its staff and student network, is virtually a mini township – and served as a market for Krea Foods' produce. In fact, the first customer for the millet-based food was the Kalinga Institute of Social Sciences (KISS) Foundation, a part of the KIIT group, which runs a residential school for 30,000 tribal children.

"A lot of people are sceptical about innovations in the food sector," says Chatterjee. The results of unhealthy eating habits do not show up instantly, "and so, most of us do not pay attention," he reckons. In his estimation, the food system in the country needs "a drastic change and I am trying to be a part of it."

Chatterjee also runs a biofuel project, which converts waste cooking oil into biodiesel; it was first taken up at KISS for experimentation, and has since been accepted by the Bhubaneswar Municipal Corporation under the 'Smart City' project.

THE REVENUE MODEL

KIIT-TBI has a seed corpus of ₹23 crore, out of which capital assistance has been provided to 86 start-ups, and ₹15.8 crore has been deployed as seed fund. These investments have seen two-fold returns in most cases – and as high as 5x in some cases.

Besides its own seed fund, KIIT-TBI has raised an additional ₹10 crore through grants and fellowships offered directly to the individual/group. Since 2012, innovators have also been getting a ₹50-lakh

grant through the Biotechnology Ignition Grant (BIG) scheme from BIRAC. So far, 120 biotech companies have received the BIG payout.

The push towards manufacturing, in particular, has attracted over 25 investors, who were impressed with the diverse sectors in which the start-ups operate, and the quality of the innovation.

Gurugram-based PadUp Ventures, an angel investor group and a mentoring platform, has been working with KIIT-TBI. It has invested in 15 innovations and mentored some 50 start-ups.

PadUp co-founder Pankaj Thakar reckons that the open innovation system at KIIT-TBI, which facilitates collective mentoring and creates a pool of investors, has given the start-ups that it incubates an edge. A start-up, he says, needs more than an idea. "It has to be structured and converted into products and services, which customers can use." Most incubation centres believe in invention, but for an invention to become an innovation, "it should have some value to the society – and some commercial value." In his estimation, KIIT-TBI has been able to "tap the right resources."

PROBLEMS AND SOLUTIONS

In some ways, KIIT-TBI's growth has mirrored that of its host city. As a Tier-II city, Bhubaneswar was still in the growth phase when the incubation centre came up; this offered a perfect setting for unfettered experimentation and innovations. The choice of Bhubaneswar among the first set of 20 cities identified for the 'Smart City' project in 2015 gave an additional boost to entrepreneurial ventures.

Mrityunjay Sahu, founder of Bariflo Labs, which was incubated at KIIT-TBI in 2018, reckons there is a counter-intuitive dynamic at work. For start-ups to grow, he says, "the location needs to have some kind of problems." As a growing city, Bhubaneswar faces a number of challenges in different sectors – and to solve these issues, "innovators like us need to come into the picture," he adds.

PHOTO: BY SPECIAL ARRANGEMENT

Mrityunjay Sahu, founder of Bariflo Labs, which offers technological solutions for aqua-farm management and was incubated at KIIT-TBI in 2018.

As a growing city, Bhubaneswar faces several challenges – and to solve them, "innovators like us need to come into the picture," says Sahu.

Bariflo Labs uses fluid dynamics and Artificial Intelligence to offer technological solutions for aqua-farm management. The project, which was to have been kick-started in Odisha, faced delayed funding, and has since taken off in Tamil Nadu and is now in deployment stage in Hyderabad. The company has its corporate offices in Bhubaneswar and Chennai, and will open one more in Hyderabad. The team is currently in talks with authorities to finalise sustainable farming projects in four cities: Jajpur, Bolangir, Berhampur and Puri.

Centres such as KIIT-TBI may have provided fertile soil for ideas to be incubated, but Bariflo Labs' experience points to a felt need for some of the start-ups to look beyond the State for their expansion. Suar reasons that a lack of sufficient investors in Odisha may account for that. "Other States have a better network of investors, which is crucial for any innovation," he points out. In fact, he adds, most of KIIT-TBI's investors are from other States. "Typically, many Odisha investors consider it risky to invest in deep science and technology projects. They are more interested in IT projects," he says.

Rahul Chatterjee, a student innovator at KIIT-TBI, started up Krea Foods, a health food initiative, and a biofuel project.

PHOTO: BY SPECIAL ARRANGEMENT

MENTORING INCUBATORS

Having established its credentials in establishing an ecosystem for innovation to flourish, KIIT-TBI is now being called upon to replicate its success elsewhere and mentor at least 10 innovation hubs in the North-East.

"KIIT-TBI can now run on auto-pilot with minimal monitoring," says Suar. That frees up planners to create mini models of the centre in other geographies. States in the East and the North-East of India have tremendous scope to grow through technology and innovations, and "our aim is to develop eastern India as an innovation hub," says Suar.

Over the next five years, KIIT-TBI will look to delve deeper into high-risk deep-technology companies. Its aim is to build a critical mass of sustainable start-ups, which may not be scalable at the moment, but can prove to be a game-changer in the future.

Now that the small acorn that was planted in 2008 has grown into a mighty oak, Suar is scaling up his ambitions for the centre. "We are now looking at bigger grants," he says. "We want to develop several companies with a turnover of ₹10-20 crore, which can then be developed into ₹1,000-crore companies."

An entrepreneurial force has been unleashed in India, he senses, with the same far-sighted vision he had back in 2008. "And we want to build a conducive environment for more start-ups to flourish." •

Only the nimble survive

How organisations respond to disruptive technology change will determine their standing in a post-COVID world.

One of the positive side-effects of the COVID crisis has been a rapid acceleration in the adoption of digital technologies across sectors. People's behaviours have also changed significantly with more than a year of remote working and learning. Several important questions arise. How many of these changes in behaviours are permanent? How fast will the digital transformation proceed? Will businesses be able to respond and leverage the new opportunities adequately? While it is still too early to have definitive answers to these questions, understanding a simple framework for the transformational impact of technology may be useful.

When a new technology arrives, the first-order impact of the new technology is *substitution* of the old technology by the new. For example, when the automobile was invented, people replaced travelling by horse carriages with travelling by car. Similarly, when the cellphone was invented, people replaced fixed-line calls with cellphone calls.

The second-order impact of new technology is *diffusion*. This happens because usually the new technology is better, cheaper and more effective, and so more and more people start using it. We saw this with the increased adoption of cars and cellphones a few years after their invention.

The final and third-order impact of new technology is *transformation* – when the ways in which people live and work get fundamentally changed due to the widespread adoption of the new technology. To continue with the car example, shopping malls and suburbs came up in many developed economies because families could drive to shop or commute from home to their workplace. Similarly, cellphones have changed many aspects of the way we live and work in society. Few of these far-reaching changes could have been predicted when the technologies were invented.

With the COVID crisis, we have seen a rapid acceleration in the substitution and diffusion phases in the context of the above framework. For example, remote learning replaced (*substitution*) in-person learning in schools and colleges around the world (*diffusion*) for months. What we have not yet seen is the full transformational impact of this digital acceleration.

DISRUPTIVE TECHNOLOGY

One of the subjects I discuss with students is how organisations respond to disruptive change, especially disruptions caused by technology. The short answer: in general, poorly. Clayton Christensen was one of the first business researchers to point out that industry leadership changed each time there was a disruptive change in the underlying technology.

Christiansen explained this brilliantly in *The Innovator's Dilemma*. The core insight of his book was that industry leaders usually resisted investing in disruptive technologies; instead, they allocated resources to current clients who demanded increasingly sophisticated features in products based on the current technology. As a result, incumbent leaders failed to make investments in new disruptive technology – but new challengers adopted and developed it aggressively. When the new disruptive technology became mature for large-scale adoption, customers shifted to the challengers, who had the best expertise in the new technology. The erstwhile leaders lost their leadership as they could not meet customers' needs with the new disruptive technology. Industry leadership shifted from the incumbent to the challenger.

Companies typically respond to the challenge of disruptive technology changes in two ways: inside-out innovation and outside-in innovation. Inside-out innovation refers to approaches that seek to foster disruptive new ideas from within the organisation – usually by promoting innovation and entrepreneurship within the corporation. Many firms also set up internal venture capital funds to fund new start-up ideas by employees.

In contrast, outside-in approaches rely upon forming partnerships with, learning from and acquiring external companies, usually start-ups with disruptive new ideas. Cisco was one of the first tech companies to change its corporate innovation strategy from internal R&D to external R&D acquisition through mergers and acquisitions. In recent times, this focus on learning and innovating from the outside has been accepted as the fastest and most reliable way to bring disruptive new products and technologies into the organisation.

LOOKING BEYOND

If we can learn from other industry sectors that have gone through this disruption process, one insight is important: we will not succeed in innovating at a fast-enough pace to leverage all the new possibilities if we only focus on innovating from the inside. We have to look outside our organisations for disruptive and innovative business models. We have to look at innovative start-ups that are creating learning models with new technologies, and we have to partner with technology leaders to create new learning partnerships. We have to launch new innovative models and experiment and learn in rapid cycles. We have to resist the pressures to continue to invest solely in current business lines and existing customer segments. We have to venture into new products and customer segments that may look very different initially from our current business profile. Doing this will not be easy, and there will be significant cultural barriers to overcome.

Outside-in innovation is the way of the future for true business transformation. The sooner you adopt this mantra and excel at it, the higher your chances of thriving as a leader in the face of technological disruptions. •

SOUMITRA DUTTA

Soumitra Dutta is a Professor of Management at Cornell University and the Chair of the Board of Directors for Global Business School Network. His latest, co-authored book is The World After COVID-19.

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Incumbent corporate leaders typically fail to make investments in new disruptive technology, but challengers adopt it aggressively – and go on to win leadership.

ILLUSTRATION: SHUTTERSTOCK

Diagnosis at your doorstep

A number of Indian start-ups are harnessing cutting-edge technology to take screening and diagnosis closer to patients and the point of care.

GAURI KAMATH

Some 15 million diabetics in India develop diabetic foot ulcers (DFUs) in their lifetime. Half of these become infected and need hospital care. About a million of them need amputation. These were probably just statistics, albeit grim ones, to Geethanjali Radhakrishnan until she visited a tertiary care hospital in Pune. A bioengineer with software experience and entrepreneurial ambitions, Geethanjali had an idea for a medical technology start-up and wanted to maximise its impact. In other words, she had the makings of a solution, and was looking for a big-enough problem to solve with it.

At the hospital, there had been patients from nearby villages. They had turned up years after an initially minor foot infection had festered and turned potentially lethal, leaving the doctors with no choice but to amputate. There were others whose fungal infection had been wrongly treated with anti-bacterials by a local doctor.

This was in spite of the fact that there has been a gold standard – the culture test – in existence for years, to suss out the nature of an infection and guide doctors towards the right treatment. But this test was the domain of well-equipped labs. "In low-resource settings, there was no lab to figure out the nature of the infection," Geethanjali says. Besides, even a lab result could take days. The patient would be lost to follow-up. Or the cost would discourage patients from testing, and doctors from prescribing the test. Treatment based on visual inspection could lead to irrational antibiotic use while crucial time was lost. For DFUs, the earlier the intervention, the greater are the chances of healing.

Geethanjali had found the problem: the absence of rapid, accurate screening for wound infections at the point of treatment. Early last year, the company she founded, Adiuvo Diagnostics, launched Illuminate, a portable, handheld, machine learning-enabled imaging device, initially targeted at DFUs. Simply put, it uses imaging and fluorescence to highlight which parts of the wound are infected, and claims to identify the broad category of infection – bacterial or fungal, gram-positive or gram-negative – with over 85% accuracy, helping doctors choose appropriate treatment and monitor healing. The turnaround time is just a couple of minutes.

MOBILE MEDTECH

Illuminate is part of an emerging area of medical technology known as point-of-care (PoC) testing. Literally, PoC techniques take testing/screening to the doctor's cabin or the patient's bedside – the places where care is typically provided. However, in countries such as India, with limited lab infrastructure, PoC may be read to include even near-care testing that is distributed beyond the large central labs – to smaller, neighbourhood labs, primary healthcare centres, or even mobile health vans.

As self-care and a focus on wellness gain currency in urban India, the term may be expanded to cover home testing, too. What's

Geethanjali Radhakrishnan of Adiuvo Diagnostics, with Illuminate, the machine learning-enabled imaging device that can screen for diabetic foot ulcer infections.
PHOTO: BY SPECIAL ARRANGEMENT

PHOTO: SHUTTERSTOCK

common to all scenarios is this: the solution has to be easy to transport, store and use with minimal or no additional training. The results should be quick and reliable. A single platform can be used for a range of applications. For instance, Illuminate can also be used in burn-related infections.

In the last few years, start-ups working on different types of technologies – from a lab-on-chip to breath-based screening – have emerged. "In a country as big as India, you cannot have only a centralised lab system where you – or the sample – are travelling hundreds of kilometres," says Sahil Jagnani, founder and CEO of Primary Healthtech, an IIT Guwahati-incubated start-up. "PoC is the solution." Jagnani's company has developed a lightweight and portable device that uses paper-based strip tests to measure functions of the kidney, liver and pancreas in under two minutes.

"I see a bright future in the early diagnosis market," says Jilma Peruvangat, co-founder and CEO of Pune-based Kozhnosys, which has a prototype of CanScan, a compact device that uses exhaled breath to screen for pre-symptomatic breast cancer. CanScan can potentially be placed in smaller diagnostic centres and hospitals, she says. Like Geethanjali, Jilma found the "pain point" after meeting women diagnosed in Stage 2 – that is, only after symptoms appeared. In small studies, CanScan had a 90% accuracy rate, with results in under 10 minutes, says Jilma. This needs to be borne out further in clinical validation.

Unlike in a central lab, where there may be trained staff, it may be a paramedic or a patient who is using the point-of-care diagnostics device.

UNMET NEED

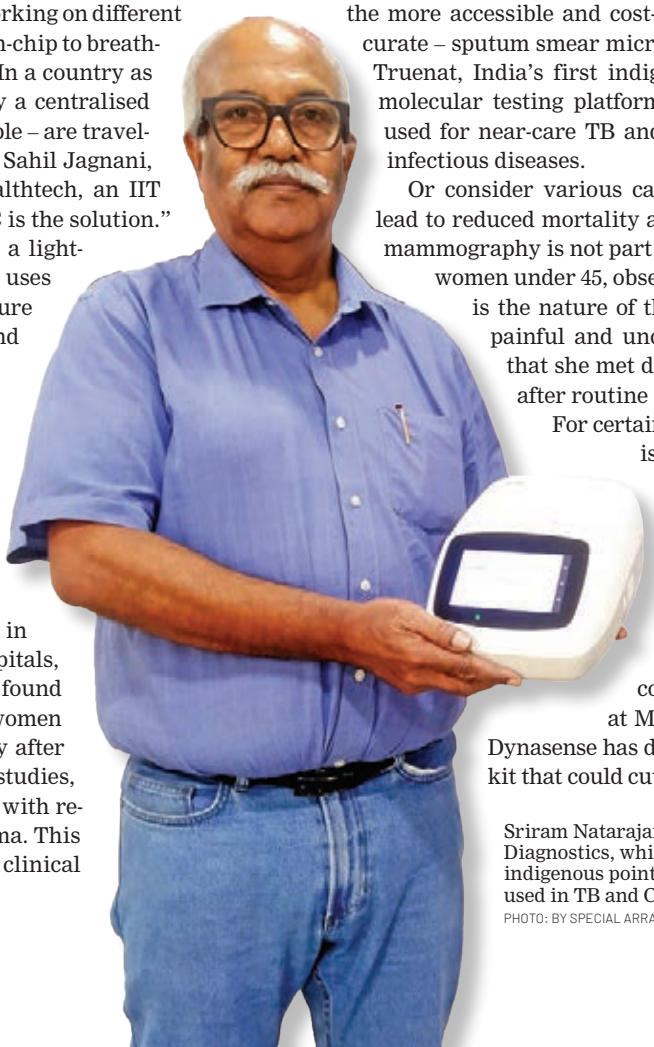
Several factors make a case for such solutions. One is the growing body of evidence that for many diseases, early detection-plus-treatment results in much better clinical outcomes. The second factor is the public health advantage. The third is the battery of tests that now count as routine with the rising global burden of non-communicable diseases such as diabetes and cardiovascular disease, and the accent on wellness and self-care.

However, conventional technologies were not designed for rapid turnaround or distributed deployment. Consider PCR (Polymerase chain reaction), a molecular testing technology commercialised in the 1990s, which heralded a change in the detection of infectious diseases owing to superior sensitivity and specificity. It punched below its weight in India. Performed by a bulky machine costing lakhs of rupees, with each test costing ₹4,000-7,000, it was limited to well-capitalised central laboratories. It was an expensive diagnostic technology to acquire and run, needing trained staff. Samples had to be ferried from collection centres all over the country, without being contaminated, to central labs to maximise throughput. A result could take three to 10 days depending on the location.

Rather than rely on it, "doctors would treat empirically," says Sriram Natarajan, founder director and CEO of Molbio Diagnostics. "As a result, in spite of being the most reliable diagnostic, people could not really benefit from it." For instance, for a high-burden disease such as tuberculosis (TB), India relied on the more accessible and cost-effective – but relatively less accurate – sputum smear microscopy. In 2018, Molbio launched Truenat, India's first indigenous and fully automated PoC molecular testing platform or micro-PCR. Truenat is now used for near-care TB and COVID-19 testing, among other infectious diseases.

Or consider various cancers where early detection can lead to reduced mortality and less radical treatment. Breast mammography is not part of routine screening packages for women under 45, observes Jilma. An additional barrier is the nature of the test itself, which is seen to be painful and uncomfortable. Among the patients that she met during her research, none came in after routine screening.

For certain kinds of tests, imported PoC tech is available, but could be expensive. For instance, a good quality home cholesterol analyser costs ₹10,000-15,000 with recurring consumables (such as the strip and lancet) costing ₹1,000 per test. "This is not viable for the end-user," says Anurag Meena, co-founder and System Architect at Mumbai's Dynasense Technologies. Dynasense has developed the prototype for a home kit that could cut the per-test cost to a third.



Sriram Natarajan, founder director and CEO of Molbio Diagnostics, which is behind Truenat, India's first indigenous point-of-care molecular testing platform used in TB and COVID-19 diagnosis.

PHOTO: BY SPECIAL ARRANGEMENT

In parallel, there is also an emerging class of "people willing to pay for convenience" in certain situations, says Dhananjaya Dendukuri, co-founder and CEO of Bengaluru-based Achira Labs. Its flagship lab-on-chip platform runs rapid immunoassays on a benchtop device. Achira wants to install this in distributed settings such as doctors' offices or in-vitro fertilisation clinics to run hormone tests that are currently in clinical validation.

THE ENABLERS

While the core diagnostic technology may have changed little in the last few decades, incremental advances in fields such as materials, electronics and computing have reportedly helped the cause of PoC. Machine learning and AI are also put to work.

Take Illuminate from Adiuvo. This is a multi-spectral imaging device. It shines light from multiple wavelengths onto the wound and collects images. Bacteria or fungi present on an infected wound fluoresce under this light, revealing infected portions. An AI algorithm matches the fluorescence to a database – generated from hundreds of trial samples – to identify and classify the infection.

Advancements in mobile diagnostics and smartphone-based imaging have helped in miniaturising multi-spectral imaging, says Geethanjali of Adiuvo. AI was used "to develop a self-training model that can quickly analyse various parameters, to help in real-time diagnostics," she says. The next step is to narrow down an infection to a specific genus such as staphylococcus, she adds.

Others, such as breath-based testing, have been helped by advances in analytical instruments. Disease can lead to a change in the concentration of organic compounds or form new compounds in exhaled breath. CanScan uses gas chromatography sensors, which are now refined enough to diagnose parts per trillion, to detect these, Jilma explains. They can potentially diagnose a range of cancers.

At Achira, building on advances in microfluidics, its lab-on-chip platform ACIX200 uses substantially lower volumes of sample and reagent to get lab-standard results and test for multiple analytes at the same time. Microfluidics are also used in Truenat's consumables.

And at Dynasense, Meena's team would like to strip down its Bluetooth-enabled device into a small block that can be attached to a regular smartphone. This way, says Meena, power and computation can be outsourced to the phone, doing away with the need for a separate screen or battery. A smartphone app will register and record readings. There is also a plan to use software from a sister company, Neodocs, to analyse the results, explain the findings, and make diet and lifestyle recommendations.

Government funding from the Department of Science and Technology, the Department of Biotechnology and the Indian Council of Medical Research is available to take start-up ideas in PoC upto proof-of-concept stage, says Rohit Srivastava, Professor of Biosciences and Bioengineering at IIT Bombay, whose lab developed the assays in Dynasense's kit. "Translational projects in PoC diagnostics are easily funded."

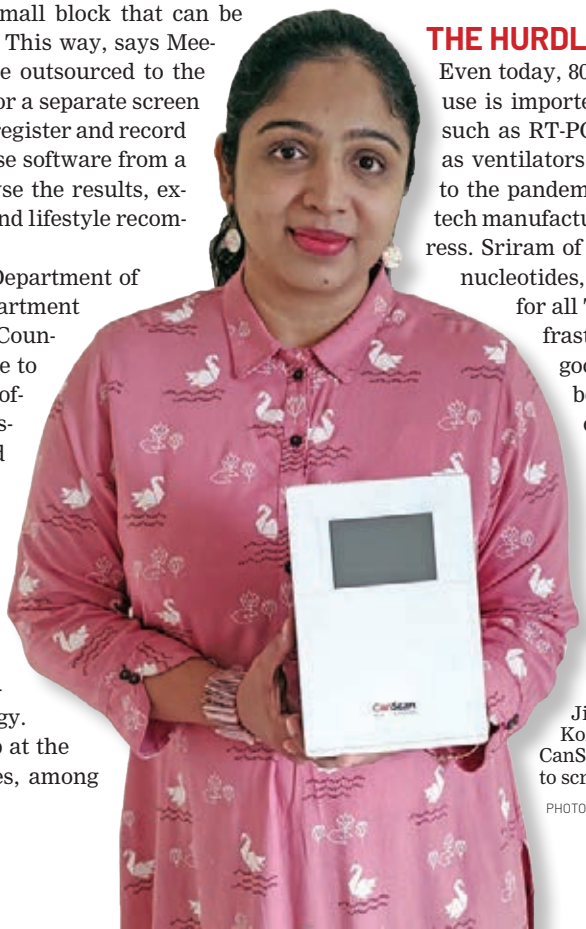
There is growing academic interest in PoC techniques, says Vivek Borse, Professor in IIT Guwahati's Centre for Nanotechnology. Borse set up the NanoBioSens Lab at the Centre to research PoC techniques, among other things, and is working on such a technique for oral cancer using blood and/or sputum. "India is in a sweet spot," he says. "We have plenty of patients, many researchers on PoC techniques that are in a good position to collaborate with start-ups." Borse is in talks with Jagnani of Primary Healthtech about solutions emerging out of NanoBioSens.

Manufacturing has also received a boost with the establishment in 2016 of the Andhra Pradesh Medtech Zone (AMTZ), which has manufacturing and testing facilities for medtech companies. Soft loans are offered from the Technology Development Board in the Department of Science and Technology. AMTZ has proved valuable during the pandemic as a location to ramp up manufacture of reagents and equipment for COVID-19 testing, including for Molbio's Truenat.

THE HURDLES

Even today, 80% or more of the medical technology in use is imported. And while capacity in specific areas such as RT-PCR test kits or hospital equipment such as ventilators may have been ramped up in response to the pandemic, a fully developed ecosystem in medtech manufacturing is still something of a work in progress. Sriram of Molbio says that it continues to import nucleotides, which are the primers or starting point for all Truenat tests. "It needs expertise and infrastructure to make primers at consistently good quality," he says. "And while it can be done, nobody talked about doing it because the market was too small."

Geethanjali of Adiuvo points out that Illuminate needs customised LEDs of specific wavelengths, but local companies cannot support those specifications. "We depend on the U.S., China, Korea," she says. Her company also imports hardware boards, although camera chips are sourced from local vendors.



Jilma Peruvangat, co-founder and CEO of Kozhnosys, which has developed a prototype of CanScan, a compact device that uses exhaled breath to screen for pre-symptomatic breast cancer.

PHOTO: BY SPECIAL ARRANGEMENT

PHOTO: SHUTTERSTOCK

Point-of-care techniques literally take testing to the doctor's cabin or the patient's bedside.

For start-ups that are still in the clinical validation phase, the lack of scale can become a stumbling block to procure inputs, says Jagnani of Primary Healthtech. After scouting in vain for a supplier of a specialised electrode, his team made it themselves even though it was a time-consuming process.

Additionally, go-to-market funding is a challenge. In addition to the government, start-ups have been mostly supported, with some exceptions, by impact funding agencies such as social enterprise incubator Villgro, and Grand Challenges Canada. Jilma of Kozhnosys, who has been attempting to raise funds from angel investors for clinical validation of the CanScan prototype, says, "The usual response is that they would like to invest in companies that already have traction or a product in the basket."

Then there is the regulatory landscape that must be navigated. India has a strange dichotomy when it comes to medical technology. On the one hand, dubious tests, including imports, abound in the private market with hardly any clinical validation. At the Apollo Hospitals group, which is a big user of PoC in its health screening initiatives, Dr Sushma Pathak's team evaluates five such solutions each day, but ultimately rejects a majority of them. "While there is a need for PoC solutions, these need clinical backup," says Pathak, Senior Program Manager, Apollo TeleHealth.

On the other, for those who want to do it right, the regulatory process sometimes feels like a black box. "There is a need for a clear-cut process to get certification," says Jagnani of Primary Healthtech. While India's relatively recent medtech rules clearly group devices according to risk classes, the actual process follows different pathways depending on the category of device and its proposed use. For many devices, regulation is still being phased in, and companies are urged to follow voluntary certification for market acceptance and to prepare for eventual regulatory approval.

Companies too have to realise the importance of rigorous clinical validation, says Chandrasekhar Nair, Chief Technology Officer, Molbio, whose company Bigtec Labs (now a Molbio subsidiary) first envisaged the micro-PCR platform in 2005. "The PoC community must realise that it (generating evidence) is going to be a massive task especially if the goal is public health programmes," he says. It took three years for Truenat to be validated for use in India's TB programme.

There is an additional consideration with PoC tests, says Sriram of Molbio. "Unlike in a central lab, where there is trained staff, here it could be a paramedic or a patient using the test, and so there is significantly more responsibility (on the provider)." It is also necessary that they address a clear, unmet need if they truly want to make an impact, he says. Geethanjali of Adiuvo is aware of this. Her company, which has supplied Illuminate to various hospitals, is proposing a study of outcomes – such as differences in antibiotic use and time taken for wounds to close – with the use of Illuminate compared with visual inspection and culture tests in two public hospitals.

As Dhananjaya of Achira stresses, PoC approaches must be used for a limited set of tests and are not meant to entirely replace centralised testing. For instance, Truenat does not expect to replace conventional RT-PCR testing, but looks to create more accessible PCR capacity. As Molbio's Nair puts it, "no single strategy is going to fulfil the diverse needs of the country." •

HANDY EQUIPMENT

Key technologies that support point-of-care testing.

Microfluidics/Nanofluidics

What it is used for: Manipulating fluids in channels with dimensions of tens of micrometres/ nanometres.

Application: Medical diagnostics; drug discovery and delivery; artificial organs.

Used in: Lab-on-chip multiplex testing; rapid molecular tests.

Global companies in microfluidics-based testing: Abbott, Cepheid, Quidel.

Biosensors/Nanobiosensors

What it is: Biosensors are devices designed to detect or quantify biochemical molecules such as a DNA sequence, protein or metabolite. Nanobiosensors are biosensors in nano dimensions to detect miniscule quantities.

Application: Food and water contamination; medical diagnostics.

Used in: Routine blood tests; infectious disease detection; breath analysis.

Global companies using them for diagnostics: Nemaura Medical, HemoCue, Masimo, RoboScientific.

Mobile diagnostics

What it is: Adapting smartphones to sensing and diagnostics needs related to healthcare to leverage their portability, connectivity and functionality for near-care or PoC testing.

Application: Wearables for monitoring oxygen and heart rate; whole-body imaging; wound assessment.

Global companies in this space: AliveCor, Butterfly iQ, HealthIO, Luminostics.

COVER STORY

In the big league

Indian engineers are contributing to international mega science projects looking to solve the mysteries of life and space.

PALLAB ROYGUPTA

Anil Prabhakar had been working at IIT Madras for eight years when he went to see Nergis Mavalvala at the Massachusetts Institute of Technology (MIT). Prabhakar, an experimental physicist who researches on quantum optics, had been approached in 2010 by Bengaluru-based theoretical physicist Bala Iyer for interest in participation in the inchoate Indian gravitational wave project, at that time called IndIGO. Mavalvala was then part of the team that would go on to discover gravitational waves in 2015. Iyer, who had been building a team in India to participate in the gravitational wave project, thought that Mavalvala and Prabhakar should meet.

Engineers at work at the International Thermonuclear Experimental Reactor (ITER) in southern France in March 2021. Indian construction company Larsen & Toubro is manufacturing cryostat assemblies and integrating the cryostat with the reactor building. ITER, which in Latin means 'The way', is an ambitious 35-nation mega science project to prove the feasibility of nuclear fusion as a future source of energy.

PHOTO: © ITER ORGANIZATION

In 2010, when the two scientists met, the first phase of observations of the Laser Interferometer Gravitational-Wave Observatory (LIGO) had come to a close. Even after eight years of work with LIGO, scientists had not discovered the gravitational waves predicted by Einstein's General Theory of Relativity. Mavalvala, whose PhD research had resulted in an automated aligning system for the interferometer, was part of a team working on the Advanced LIGO, an observatory with a sensitivity three times that of the original set of instruments. Prabhakar came back to India impressed by the sophistication of LIGO's science and engineering. "I remarked at that time that if there was anybody doing photonics in the world and they were not involved in LIGO, there was something wrong," says Prabhakar. "You cannot *not* be involved in such a cutting-edge experiment."

Gravitational waves are ripples in space-time – space and time are taken as one entity in relativity – generated during violent events like supernova explosions or black hole mergers; the ripples travel in all directions at the speed of light, not unlike waves on the surface of a pond on which a large stone has been dropped. When they reach Earth, the waves give the planet a gentle press, squeezing it in one direction and then releasing it instantly as the waves move away. Physicists had no doubt that gravitational waves existed. But they always wondered about their ability to detect the waves.

Gravitational waves from an event a billion light-years away are extremely feeble when they reach Earth. In the interferometer that LIGO scientists have built, with two perpendicular arms each four kilometres long, one of the arms shrank in length by a billionth of a billionth of a metre when gravitational waves hit it in 2016. This shortening was measured by a small change in the interference pattern of light that travelled between the arms. Scientists had discovered gravitational waves by using the most sensitive instrument ever constructed. They are now trying to make it even more sensitive.

After he returned and LIGO-India started forming, Prabhakar set out to work on a technology that would be used in the next version of Advanced LIGO, a set of improvements that are called A+. When the third LIGO observatory – the first two are in the U.S. – is installed after 2025 at Aundha Nagnath in Maharashtra, physicists will use Prabhakar's noise-filter technique to detect the faintest of ripples in space-time. By then, a large number of scientists and engineers in India would have worked on systems of extraordinary precision for the observatory, building

As a founding member of FAIR, India is contributing heavy-duty equipment, including ultra-high vacuum chambers and superconducting magnets.

technologies that have wide-ranging applications in other fields in the future. "The LIGO-India project not only puts us in a respectful position in the field of gravitational wave astronomy, it also gets Indian companies exposed to work of high precision like building vacuum chambers," says LIGO-India spokesperson Tarun Souradeep.

LIGO is one of the six mega – giga seems a better description – international science projects that India is participating in at the moment (*see table: Reaching for the stars*). The others are a fusion reactor in France, an optical telescope in Hawaii, a network of radio telescopes in multiple countries, the Large Hadron Collider (LHC) in Europe, and an antiproton research project in Germany. Along with these international projects, India has been working on its own big science project: the India-based Neutrino Observatory (*see box: Observing the mysterious neutrinos*). Some of these projects are in the early stages of their formation, but 90 Indian institutions, over 800 scientists and 60 companies are participating in them.

Together, they are pushing the boundaries of the possible and developing technologies that are expected to provide spin-off benefits to a wide range of indus-

At the FAIR accelerator facility, where scientists are working on an experiment to create particles that exist mostly in the depths of space.

PHOTO: J. HOSAN/GSI

tries. "Big data, software development and technology transfer are all involved in any mega science project. They help in the overall development of the country," says Shashi Bhushan Pandey, scientist at the Aryabhatta Research Institute of Observational Sciences (ARIES) in Nainital. Add new engineering and science to big data, and we get a vision of commercial technology two decades from now.

The aim of these projects, barring the construction of the fusion reactor, is to answer fundamental questions of nature. How did the universe come into existence? How is it evolving and where will it end finally? What are the building blocks of matter? There are two ways to answer these questions, both deep. One is to investigate the smallest constituents of matter and look deep inside the atom.

PHOTO: BY SPECIAL ARRANGEMENT

Dr Sibaji Raha, Chair of the FAIR India Scientific Council and former Director of the Bose Institute, Kolkata.

At FAIR, particles will be accelerated to high speeds to study physics – from the creation of the universe to present-day material science applications.

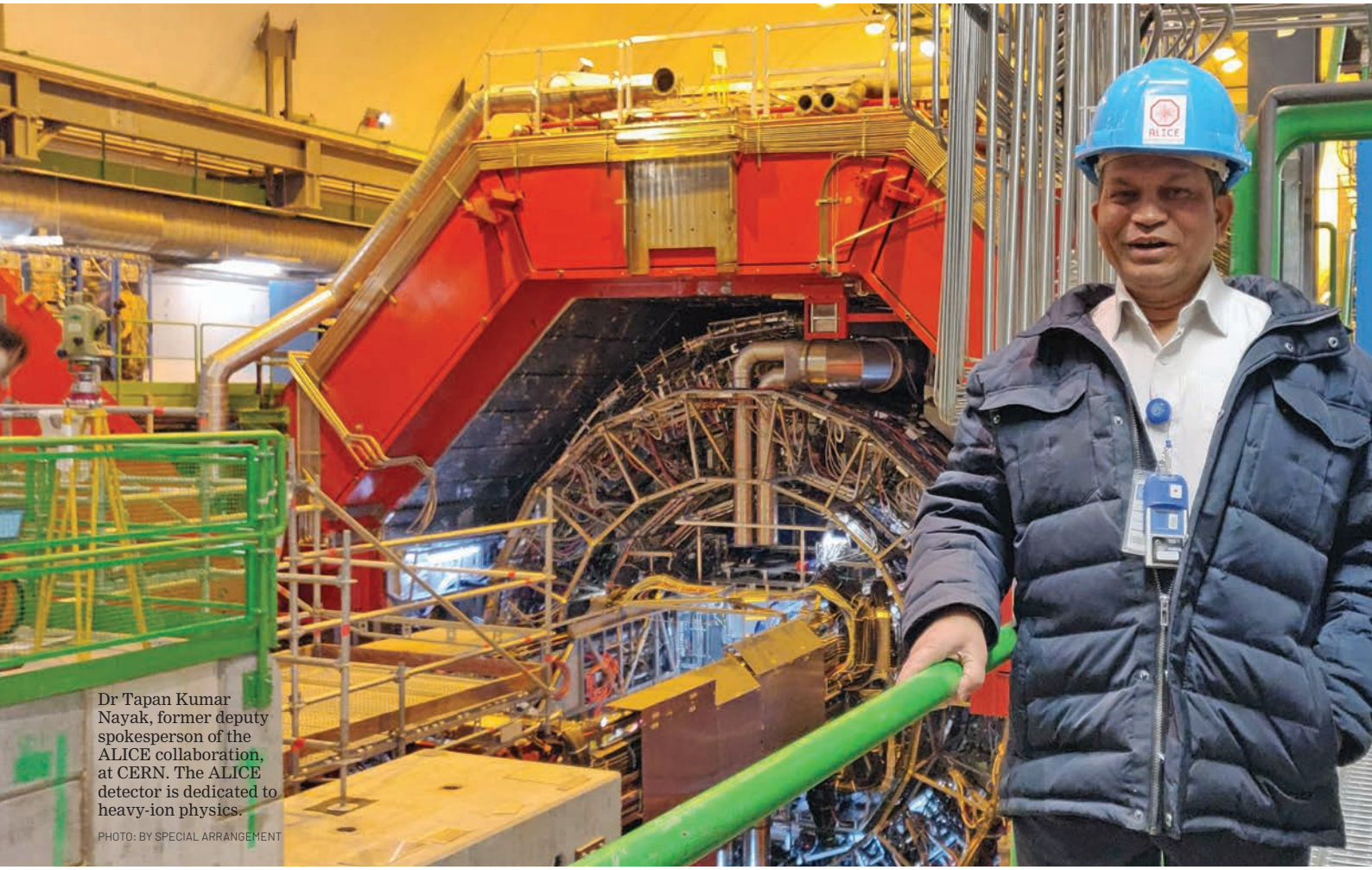
The other is to look far ahead into deep space and into the distant past. The first often involves creating conditions that do not exist on Earth, as a way of mimicking the conditions of the early universe. The second method involves detecting the feeblest of whispers from the early universe, to find signatures of events that happened soon after the universe was formed.

Both methods require the development of technologies that are too expensive or too difficult for private companies but very useful to them when ready. For Indian industry, which was secluded for long from cutting-edge research, participation in big science projects is a rite of passage and a chance to learn engineering techniques that are at least a generation ahead. Some Indian companies are exploiting the opportunity with an eye on the long-term benefits. "What we found is that Indian companies look for the future significance of their participation over financial reward," says Yashwant Gupta, director of the National Centre for Radio Astrophysics (NCRA).

SLOW AND STEADY

Participation in international science projects is not a new phenomenon for India. Indian scientists have been participating from the 1970s in projects of the European Organization for Nuclear Research (CERN), which conceived the LHC four decades ago as an underground facility to smash particles at velocities close to that of light, creating conditions that existed only at the birth of the universe. India formally joined the LHC project in 1991 and had a significant role in the project through the 1990s and the early twenty-first century, both in science and engineering, with participation from about 400 scientists.

Avasarala, a company set up in Bengaluru in 1985, had started working for the LHC in 2005. It had initially participated in the construction of a part of the collider by manufacturing 7,080 precision magnet positioning jacks on which the 27-kilometre-long circular collider tube is placed. Each of these magnets weighs 32 tonnes, but the jacks maintain the position of the magnets to an accuracy of 0.05 millimetres even when they are subject to forces all around. Avasarala's work on the LHC brought more work for the company: for



Dr Tapan Kumar Nayak, former deputy spokesperson of the ALICE collaboration, at CERN. The ALICE detector is dedicated to heavy-ion physics.

PHOTO: BY SPECIAL ARRANGEMENT

the telescope in Hawaii, the fusion reactor in France, and the antiproton experimental facility in Germany.

The Indian participation in the LHC project has been mainly for its two large detectors: A Large Ion Collider Experiment (ALICE) and the Compact Muon Solenoid (CMS). Detecting a new particle whizzing around at the speed of light in a sea of other particles is not an easy task. To make things more difficult, some of these exotic particles are short-lived. CERN needed sensitive detectors, and its scientists invented one in 1997. Called the gas electron multiplier, it has become a key component at the LHC for detecting charged particles. The detectors are made at CERN itself, and only a small number of companies have the capability to make it at the required precision.

In 2015, scientists at the Bhabha Atomic Research Centre (BARC) asked a small Bengaluru-based company, Micropack, whether it was interested in making the gas electron multiplier for CERN. Micropack, which has a turnover of ₹67 crore now, made printed circuit boards for the military that required high reliability. This background did not automatically qualify the company for LHC; making the gas electron multiplier required a high level of precision engineering. One of the difficult tasks included making a 50-micron thick – one micron is a millionth of a metre – polyamide film that has to be punctuated uniformly with 70-micron holes. A square piece of foil of a side of 300 millimetres would require hundreds of thousands of such holes, which are not drilled but chemically fabricated.

In 2020, 144 gas electron multiplier detectors made by Micropack were installed at the LHC, and the company is now making a larger set of detectors to be installed in 2022. Meanwhile, it is searching for other applications for the technology. It is working with Delhi University to use the gas electron multiplier technology in medicine to detect cancer and focus a beam for treatment. "We do not quite know about all our opportunities," says Pradeep Menon, chief operating officer of Micropack. "Application of this technology in medicine is not proven yet."

Participation in the LIGO-India project puts Indian scientists and Indian companies on the frontlines of gravitational wave astronomy.

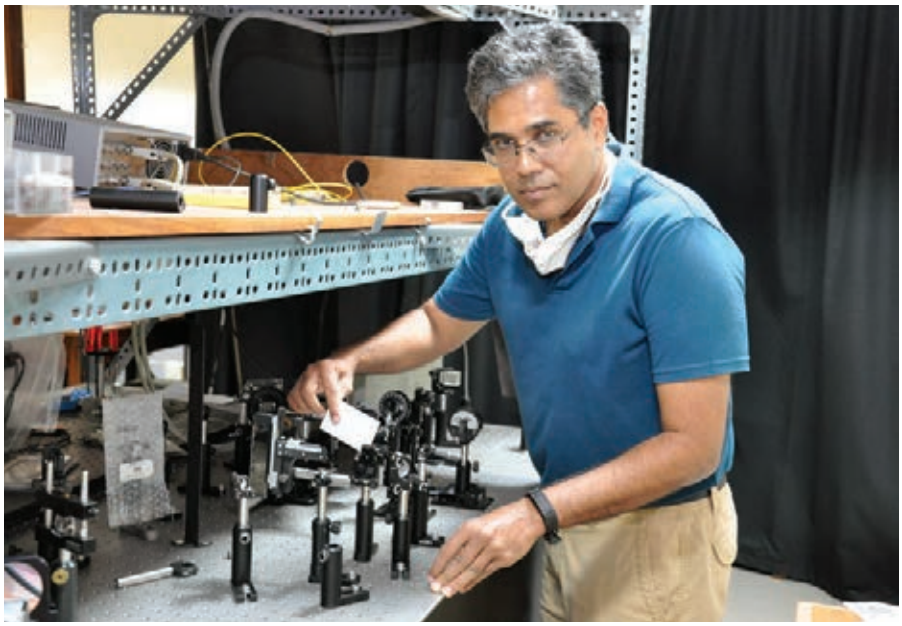
More than 20 Indian institutions and an equal number of companies now work for the LHC. About 500 km from Geneva, where the LHC is located, another set of scientists are involved in an experiment to create particles that exist mostly in the depths of space. Called a universe in the laboratory, the Facility for Antiproton and Ion Research (FAIR) at Darmstadt in Germany is another accelerator – a device that accelerates particles to high speeds – but with a scientific purpose different from the LHC. It aims to study physics, starting from the creation of the universe to present-day material science applications.

For example, one of its experiments will create on a small scale the high temperatures and pressures that exist inside stars and study how nuclei of atoms are cooked inside them. Another experiment will create antiprotons, the antiparticle of a proton, as a way of understanding mass and the strong force that binds protons and neutrons together in the atomic nucleus. A third project will create the extreme conditions, for a fleeting instant, found inside neutron stars. The fourth experiment at FAIR is to look at applications of atomic and plasma physics. The facility will have the infrastructure to create ten million particle collisions per

Reaching for the stars

Six global projects on which Indian scientists are collaborating

Project	Details	No. of Indian institutes involved	Indian participation since
CERN (European Organization for Nuclear Research)	World's largest Particle Physics laboratory. Near Geneva, Switzerland	20	1991 India collaborated in LHC project of CERN
FAIR (Facility for Antiproton and Ion Research)	International accelerator facility. At Darmstadt, Germany	30	2010
ITER (International Thermonuclear Experimental Reactor)	World's largest fusion energy facility, being set up in southern France	Institute for Plasma Research, Gandhinagar	2005
LIGO-India (Laser Interferometer Gravitational-Wave Observatory)	An observatory for detecting gravitational waves, in collaboration with LIGO-US. Coming up at Aundha Nagnath, Maharashtra	15	Govt approval secured in 2012
SKA (Square Kilometre Array)	World's largest Radio Telescope Facility, being set up in South Africa and Australia	20	2013
TMT (Thirty Meter Telescope)	One of the world's largest optical telescopes. Coming up in Hawaii	12	2014



At IIT Madras, Dr Anil Prabhakar has designed noise-filter technology that physicists will use at the third LIGO observatory. PHOTO: KANNAN KRISHNAMURTY

second, which is higher than any existing or planned accelerator in the world. Construction of the facility began in 2017.

India is a founding member of FAIR and holds 3.6% of its current shares. The country is supposed to contribute around €36 million, of which €9 million will be in cash and the remaining €27 million as equipment. In one of its early projects, the Variable Energy Cyclotron Centre (VECC) in Kolkata, with collaboration from the Electronics Corporation of India Limited (ECIL), designed and produced a high-current and stable power converter. It had taken the institution three years to conceptualise and seven years to design and manufacture from scratch. "The converter required a lot of non-trivial R&D," says Sibaji Raha, former Director of the Kolkata-based Bose Institute and Chair of the FAIR India Scientific Council. The technology for such converters can be useful in electric car batteries or future nuclear power plants.

For FAIR, India is also providing ultra-high vacuum chambers, superconducting magnets and power cables. Around 30 institutes are participating in FAIR, including BARC in Mumbai; the University of Calcutta; and Aligarh Muslim University. One of the beam catchers – a piece of equipment that absorbs the energy of particles – of FAIR was designed by the Bose Institute and the Central Mechanical Engineering Research Institute (CMERI) in Durgapur. Equipment designed in India are usually manufactured in India, and so it is an opportunity for Indian companies to manufacture the beam catcher. Bose Institute and VECC also designed the multipole magnets for the experiment to study atomic nuclei formation in stars. The two physics projects – LHC and FAIR – have significantly improved accelerator science and engineering in India. Particle accelerator technology has direct relevance for cancer treatment. "We need to learn the technology once, and then we can copy it in every state," says Tapan Kumar Nayak, former deputy spokesperson of ALICE collaboration, CERN.

While FAIR tries to create on Earth tiny representations of stars, scientists from seven countries have been trying to make stars on a much larger scale. The International Thermonuclear Experimental Reactor (ITER) at Saint-Paul-lez-Durance in France is a mini-star that will use atomic fusion to produce electricity. It is contained in a reactor called Tokamak, which magnetically confines the hot plasma in a region shaped like a torus.

India is represented in ITER by a single institution: the Institute for Plasma Research (IPR), in Gandhinagar, under the Atomic Energy Commission. India became the seventh full partner of ITER in December 2005 and contributes 9.1% of the total project cost of around €20 billion. All partner countries are to get full access to its knowledge and information irrespective of their share of the project.

The fusion reaction that produces the energy happens at a temperature of 150 to 300 million degrees Celsius. The reactor

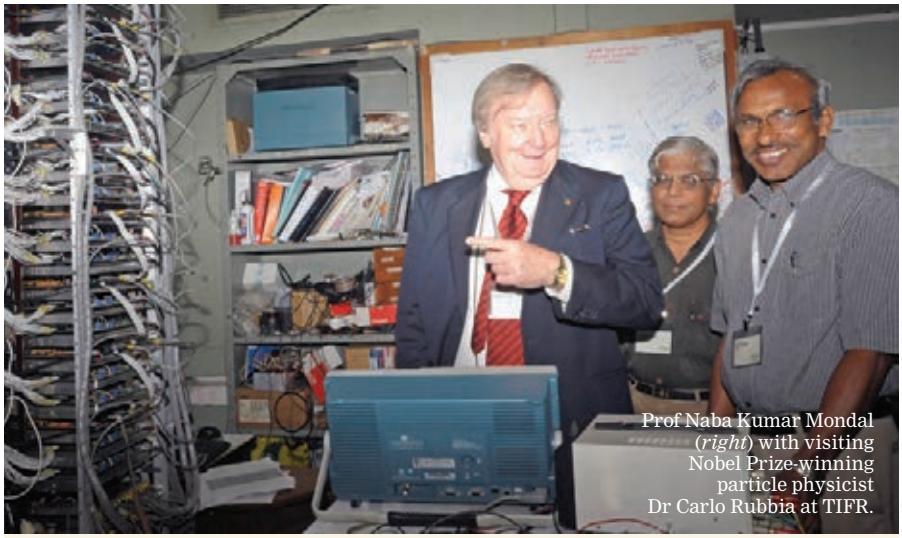
is surrounded by a 3,850-tonne cryostat, which encloses the world's largest vacuum chamber, and which has to be maintained at a temperature of a few thousand degrees Celsius. Larsen & Toubro had taken up the task of designing and manufacturing the 30-metre-wide and 30-metre-high cryostat from scratch, doing the detailed engineering, metallurgy, welding technology, fabrication technology, forming, machining, quality control, and training of the people involved in the project.

The cryostat was built in 54 modules, integrated into four large assemblies, and taken to the main reactor for installation. The company had to do one kilometre of full-penetration welding of joints, followed by several hundred metres of welding to assemble the cryostat sections in the Tokamak Pit. The lower part of the cryostat had to be installed in the reactor with a precision level of three millimetres. The virtual digital assemblies, software for distortions control and special welding techniques developed for the ITER project are now being used by L&T in other commercial projects.

STAR-MAKING TO STAR-GAZING

The largest optical telescope in India is the 3.6-metre optical telescope at ARIES in Nainital, which began observations in 2016. The previous largest was a 2.3-metre telescope at the Vainu Bappu Observatory in Kavalur, Tamil Nadu. Both are small in contemporary optical astronomy: there are 13 telescopes in the world with a mirror diameter of over eight metres. And there are at least three telescopes under construction with a diameter of more than 30 metres. When ready, these telescopes would leave Indian optical astronomy far behind. Fortunately, India got to participate in one of them: the Thirty Meter Telescope (TMT) in Hawaii.

The TMT is being built by astronomers from India, Cana-



Prof Naba Kumar Mondal (*right*) with visiting Nobel Prize-winning particle physicist Dr Carlo Rubbia at TIFR.

PHOTO: BY SPECIAL ARRANGEMENT

Observing the mysterious neutrinos

INO will help understand 'extreme events' in the universe.

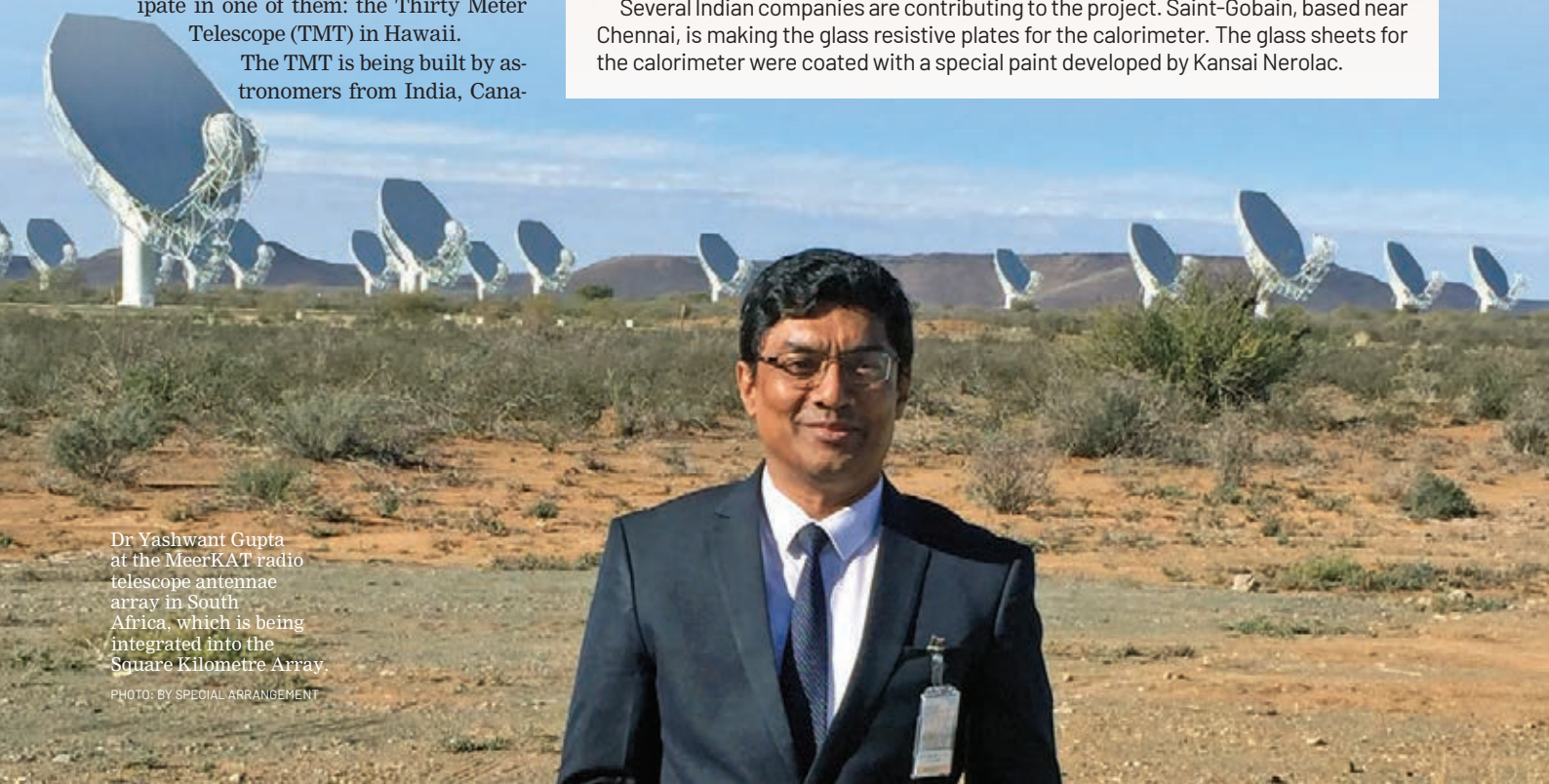
In 2001, three physicists met at the Saha Institute of Nuclear Physics (SINP) in Kolkata to discuss the possibility of a neutrino observatory. They talked all day and over beer at dinner, often about failed projects and why things didn't work in India. "After the dinner, with glasses of beer, we decided we had enough talk on failures, now let's together make it happen," says Naba Kumar Mondal, one of the three scientists and Raja Ramanna Fellow at SINP.

Their ideas morphed into the ₹1,500-crore India-based Neutrino Observatory. Neutrinos are particles of negligible but non-zero mass; some 100 trillion of them stream through the earth – and our bodies – every second. Neutrinos are among the most mysterious particles known to physicists. Their precise mass is not known. They travel in straight lines for billions of years, not stopping to interact with the matter they encounter. Because of this feature, they are one of the best objects to study to understand events in the universe. Especially the extreme events.

After a long search, scientists chose Pottipuram, in a mountainous region in Theni district of Tamil Nadu as the INO site. It was opposed by environmental activists and local politicians, but the Union Cabinet cleared it in 2015. Opposition to the project continues, but scientists are confident of starting the project soon.

The proposed lab is around a kilometre under the mountain and will have three inter-connected cabins that will house three experiments. A two-kilometre-long motorable tunnel will connect the cabins to the outside. This experiment will consist of a gigantic 51-kiloton iron calorimeter with 30,000 fast and highly sensitive particle detectors, which measure the energy of the particle as it passes through each layer.

Several Indian companies are contributing to the project. Saint-Gobain, based near Chennai, is making the glass resistive plates for the calorimeter. The glass sheets for the calorimeter were coated with a special paint developed by Kansai Nerolac.



Dr Yashwant Gupta at the MeerKAT radio telescope antennae array in South Africa, which is being integrated into the Square Kilometre Array.

PHOTO: BY SPECIAL ARRANGEMENT

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da, China, Japan, and the U.S. Like all other international projects, it will push the envelope of technology by a generation or two. It will have a 121-tonne primary mirror comprising 492 hexagonal-shaped mirrors, each 1.44 m across and 45 mm in thickness. All these hexagonal mirrors are to be mounted on a complex optomechanical system called segment support assembly, many of which are to be made by L&T. The segment support assembly aligns the mirrors to a precision of four-billionths of a metre, and this accuracy is maintained by actuators that bring the pieces back in alignment when stressed by external forces. "The accuracy level of the instrument sounds crazy," said J.D. Patil, Whole-time director of L&T.

India-TMT will provide 3,284 edge sensors required for the primary mirror segments, made by General Optics (Asia) Ltd (GOAL), Puducherry, and the Bengaluru-based Optics & Allied Engineering Pvt Ltd. Other than hardware components, Indian companies are also working in telescope control software. TMT will use adaptive optics to correct the effects of atmospheric turbulence for improved images, roughly a thousand times a second, using an extraordinarily complex technology that has now found applications in medical imaging. India-TMT is also responsible for manufacturing all the 1,526 actuators required for the project, which will bring the mirrors back in alignment after deflection due to natural events. A Jamshedpur-based company, Indo-Danish Tool Room (IDTR), made prototypes of the actuators that work to a precision of four-billionths of a metre.

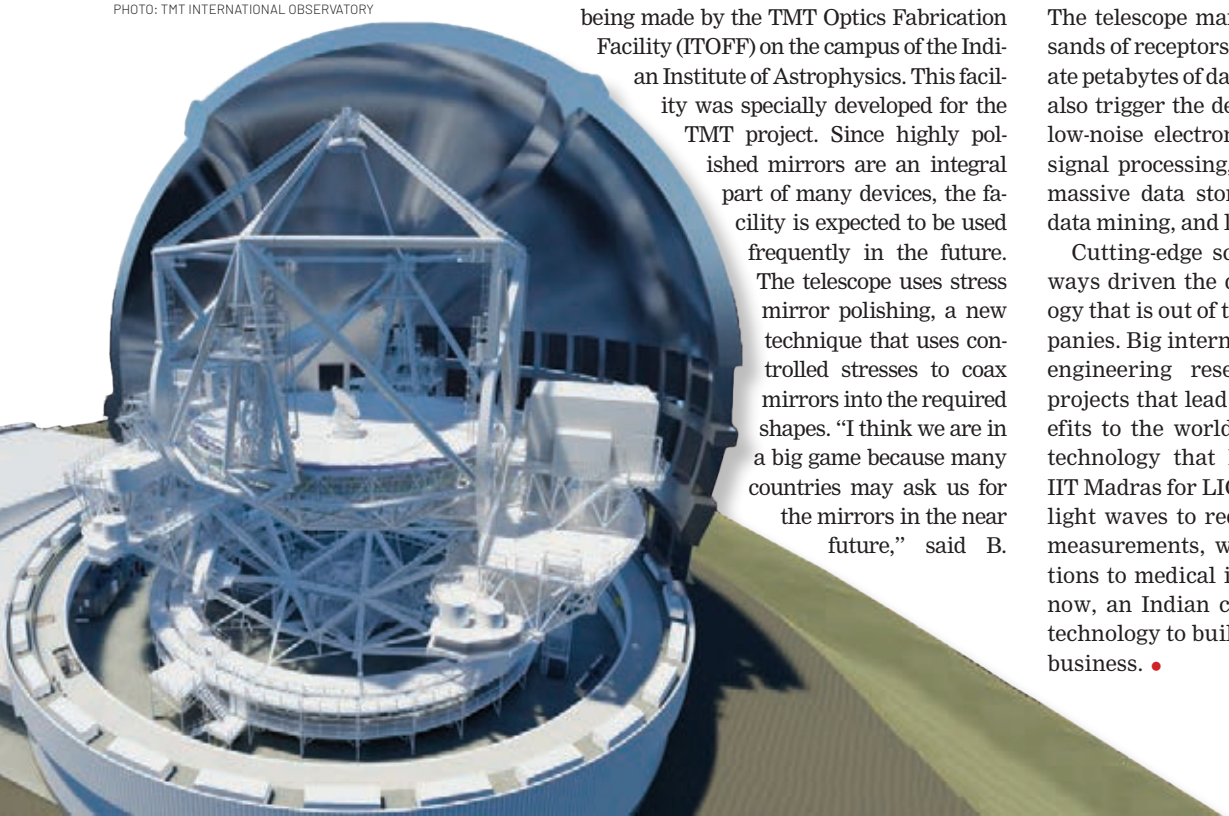
Dr B. Eswar Reddy, Director, India-TMT. The Thirty Meter Telescope project is a giant leap for Indian optical astronomers.

PHOTO: BY SPECIAL ARRANGEMENT

Astronomers from India, Canada, China, Japan, and the U.S. are collaborating on the TMT project, which will push the envelope of technology by a generation or more.

An artist's 3D rendering of the Thirty Meter Telescope, coming up in Hawaii. About 20 Indian institutions are collaborating on the project, with NCRA as the nodal institute.

PHOTO: TMT INTERNATIONAL OBSERVATORY



Of the 492 mirrors of the telescope, 84 are being made by the TMT Optics Fabrication Facility (ITOFF) on the campus of the Indian Institute of Astrophysics. This facility was specially developed for the TMT project. Since highly polished mirrors are an integral part of many devices, the facility is expected to be used frequently in the future. The telescope uses stress mirror polishing, a new technique that uses controlled stresses to coax mirrors into the required shapes. "I think we are in a big game because many countries may ask us for the mirrors in the near future," said B. Eswar Reddy, Director, India-TMT.

The TMT is a giant leap for the global astronomy community, and especially for Indian optical astronomers. On the other hand, the Square Kilometre Array (SKA) grew partly out of ideas from Indian astronomers. In 1991, Govind Swarup of NCRA-TIFR proposed a large, next-generation radio telescope, and suggested it be named the International Telescope for Radio Astronomy (ITRA); in a paper published in *Current Science* journal that year, Swarup had noted, "*itra* means perfume or essence in Hindustani". That idea has since morphed into the SKA. It consists of multiple dishes in several countries with a combined area of one square kilometre.

Most of the dishes will be at South Africa's Karoo region and Western Australia's Murchison Shire, two of the most remote and quiet locations on Earth. The unprecedented combined sensitivity of the SKA dishes, spread over hundreds of kilometres in these locations, will give astronomers insight into the formation and evolution of the first stars and galaxies after the Big Bang, the role of cosmic magnetism, the nature of gravity and dark energy, and so on. Around 20 institutions in India are collaborating on the project, with NCRA as the nodal institute.

The leading Indian contribution for the project will be the Telescope Manager (TM), being developed with assistance from two software companies: TCS and Persistent Systems. Persistent had earlier developed software for the upgraded Giant Metrewave Radio Telescope near Pune. The telescope manager will control thousands of receptors that will, in turn, generate petabytes of data. In India, the SKA will also trigger the development of antennae, low-noise electronics, analog and digital signal processing, high-speed computing, massive data storage, image processing, data mining, and large software systems.

Cutting-edge science projects have always driven the development of technology that is out of the reach of private companies. Big international projects involve engineering research at every stage, projects that lead to an avalanche of benefits to the world of industry later. The technology that Prabhakar develops at IIT Madras for LIGO, a method to squeeze light waves to reduce the uncertainty of measurements, will have direct applications to medical imaging. A decade from now, an Indian company could use that technology to build a sophisticated global business. •

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India's bumpy road to 'net zero'

The path to 'net zero' carbon emissions is challenging, and realising it will require a generational shift in technology use.

Vaidik Dalal
howindialives.com

Some 137 countries have committed themselves to becoming carbon-neutral by 2050. China, the world's largest emitter of carbon, has pledged to achieve carbon-neutrality by 2060, and the United States by 2030. India, so far, has not pledged a specific target, but has promised to abide by the Paris Agreement to decrease its emissions intensity 30-35% from 2005 levels by 2030.

Collectively, achieving 'net zero' carbon emissions by 2050 is critical in the effort to limit the rise in global temperatures to 1.5° Celsius, against the current trajectory of 2.1° by 2100. As a developing nation, India faces a severe challenge in managing its carbon emissions while pushing economic growth.

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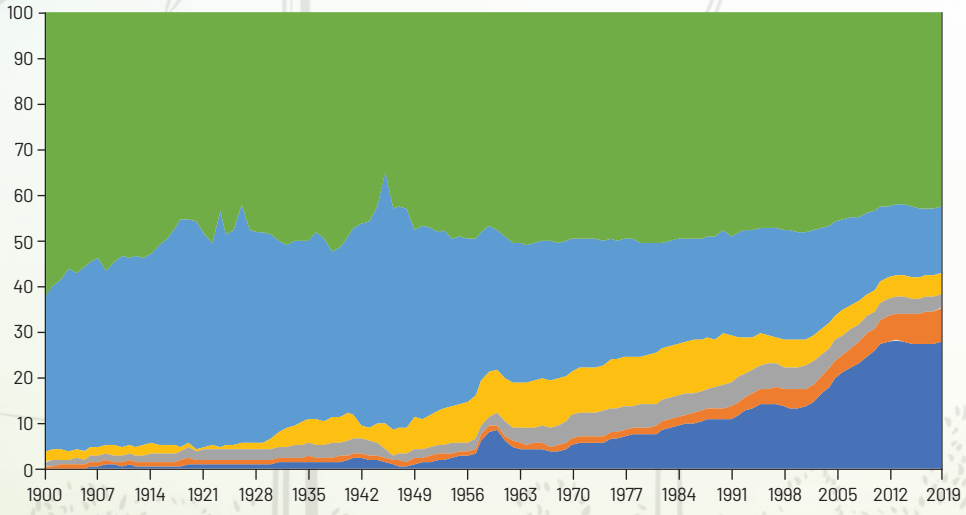
India's challenge

India today accounts for about 7% of total global carbon emissions. This is about one-fourth that of China and half that of the United States. India's carbon emissions have grown at a faster rate since India opened up its economy in the early 1990s and moved to a higher growth trajectory. In the last decade, India's carbon emissions grew at a compounded annual rate of about 5.1%.

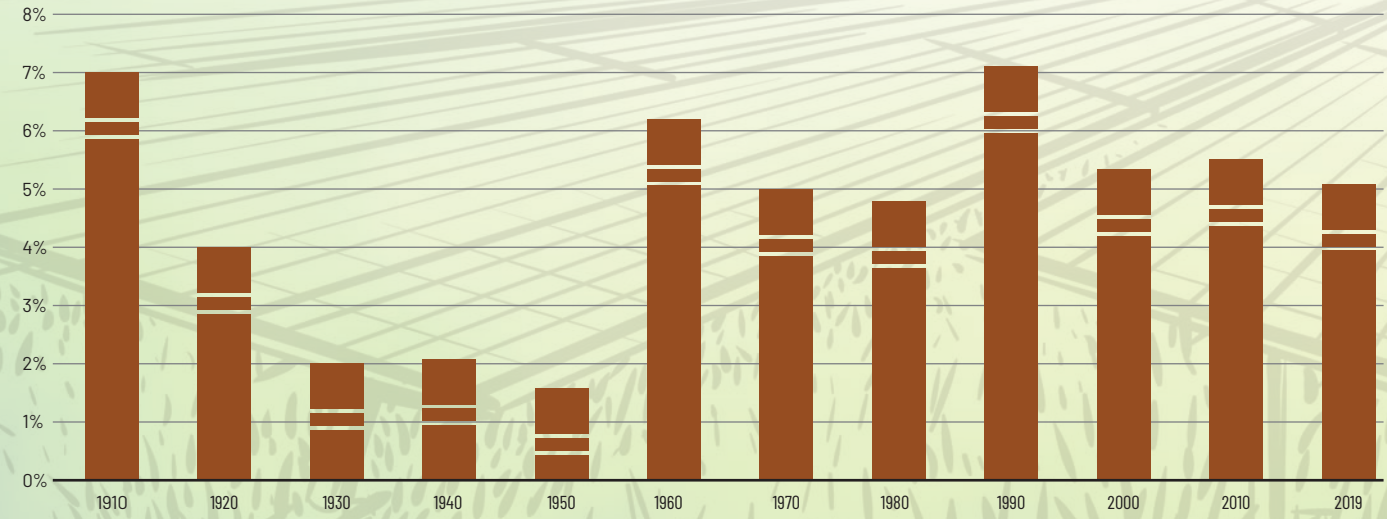
Country-wise share in global carbon emissions

Share in global carbon emissions (%)



Growth in India's carbon emissions

Compounded decadal growth in India's carbon emissions (%)



Source: Global Carbon Project (sourced from Our World in Data)

Sources of emissions

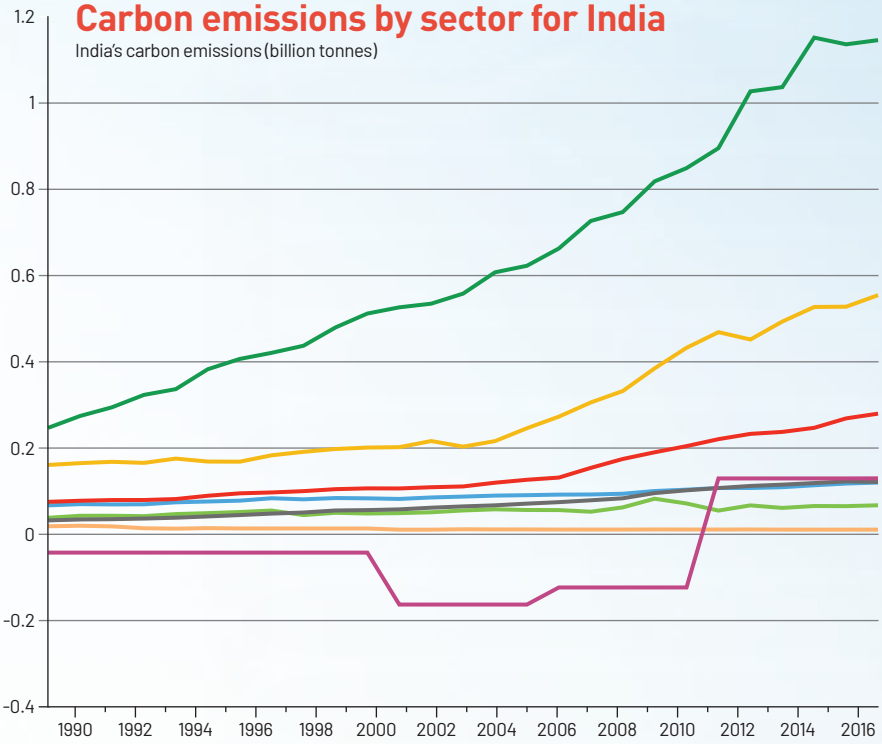
As of 2016, electricity and heat accounted for 48% of India's emissions. This was followed by manufacturing processes (23%) and transportation (11%). In other words, the power sector is the key prism through which to see India's efforts to reduce emissions.

Beyond consumption, there are two levers that countries can use to reduce emissions. The first is exports, as emissions are recorded in the country of consumption, not in the country of production. This construct helped India reduce its carbon emissions by 0.3% in 2019. By comparison, China, the world's largest exporter, offset its emissions by 9%.

The second is forest cover. Forests absorb carbon and create what, in the context of carbon emissions, is called a 'carbon sink'. Between 1990 and 2010, India was able to reduce its carbon emissions through this source. However, with progressive deforestation and change in land use, this head now accounts for a 5% share in India's carbon emissions.

Carbon emissions by sector for India

India's carbon emissions (billion tonnes)



Electricity & heat · Manufacturing · Transport · Land use change and forestry · Industry · Building · Other fuels combustion · Fugitive emissions

Source: Global Carbon Project (sourced from Our World in Data)

Renewable status

From a source perspective, coal-based sources account for two-thirds of carbon emissions. This has consistently exceeded 60% since 2004, underscoring India's high dependence on coal. It is followed by oil (25%). To achieve carbon neutrality, moving to alternatives for coal and oil is critical.

Renewable sources of energy, like solar and wind, are the alternative. As part of the Paris Agreement, India has pledged to achieve 40% of its electricity capacity through renewable sources by 2030, against 25% currently.

The Indian government has set a target to increase renewable energy capacity to 450 GW by 2030 – about five times the current renewable capacity. An intermediate target in this is 175 GW by 2022. On the basis of the incremental growth in the past five years, India is likely to miss this. The big push has to come from solar, whose share in renewable energy capacity has increased.

India's power generation capacity by source

Share of generation capacity (%)

Thermal Energy

Coal **52.9** · Gas **6.5** · Lignite **1.7** · Diesel **0.1**

Non-thermal/Non-renewable

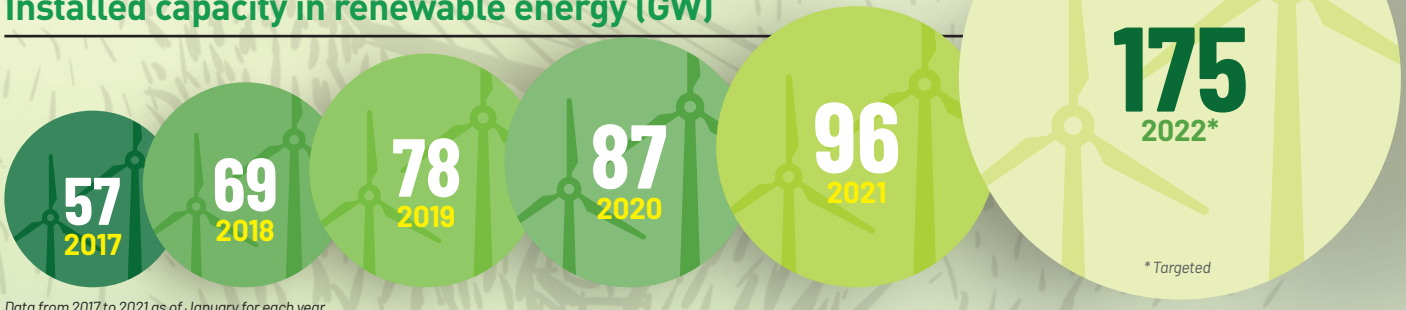
Hydro **12.1** · Nuclear **1.8**

Renewable

Solar **10.7** · Wind **10.3** · Biopower **1.7**

Small Hydro **1.2** · Waste **0.0**

Installed capacity in renewable energy (GW)



Data from 2017 to 2021 as of January for each year
Renewable energy sources here include solar, wind, small hydro, biomass, and urban & industrial waste.
Source: Central Electricity Authority

PHOTOS: SHUTTERSTOCK

Renewable shift

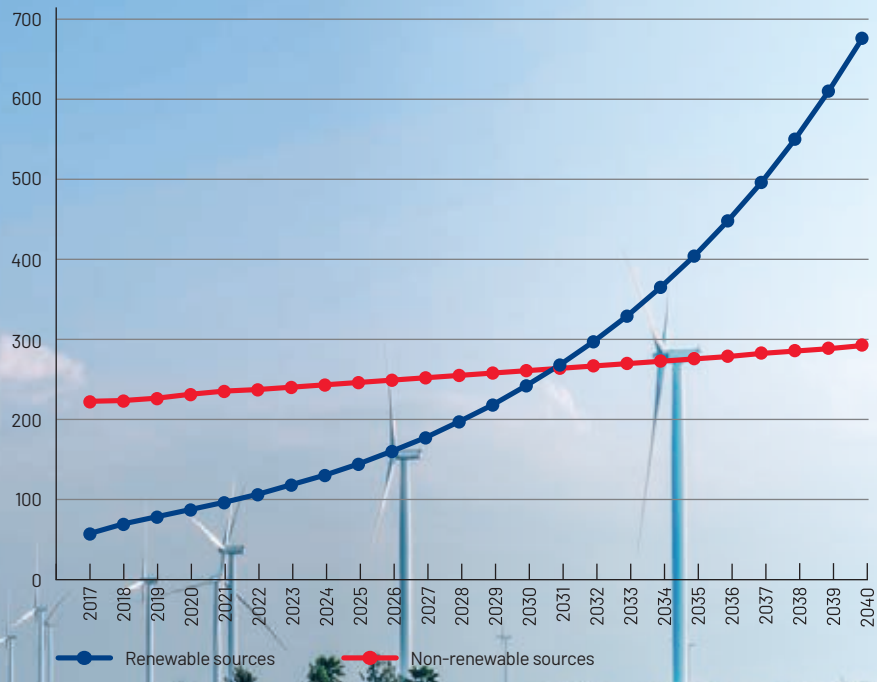
According to the European Parliament, carbon neutrality can be achieved through a balance between emitting carbon and absorbing carbon through carbon sinks. To date, no artificial carbon sinks are able to remove carbon from the atmosphere on the necessary scale to fight global warming.

Another approach to net zero emissions is carbon offsetting: offset emissions in one sector by reducing them elsewhere. That's what sources of renewable energy do. As of 2021, renewable energy accounted for about one-fourth of India's total power capacity. But in the past five years, renewables have grown at a faster pace than non-renewables: compounded annual rate of 10% versus 1.1%. Assuming these rates hold, the two will be at par on capacity by 2031. And by 2040, renewables will be double of non-renewables.

According to the India Energy Outlook 2021 report, India is on course to reach net zero emissions only in the mid-2060s.

Installed capacity projections for India on current growth rates

Installed capacity (GW)



Note: Data from 2022 onwards are projections assuming each segment maintains respective growth of the last five years.
Source: Central Electricity Authority

PHOTOS: FREEPIK

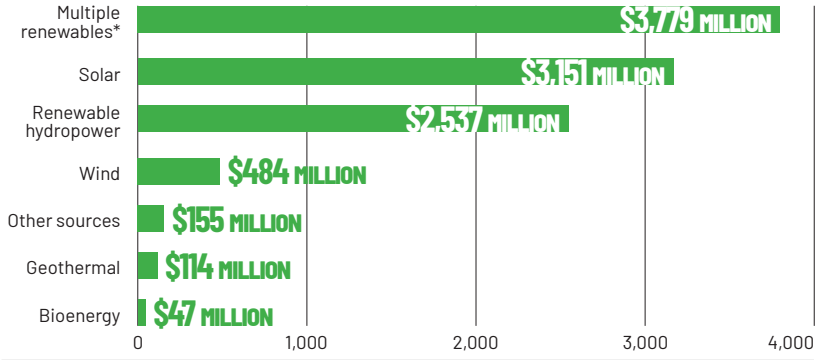
Financing carbon neutrality

One challenge to scale up renewable capacity is funding. The scale at which India's energy production, storage and distribution capacity will need to grow to meet the carbon-neutral goal is one that will require foreign funding. Be it generation of renewable energy, technology adoption for electric vehicles or distribution network of batteries. Since 2000, India has received $10.3 billion in foreign funding for renewable sources. Only Brazil ($42 billion) has received more. About 31% has gone into solar.

Currently India devotes nearly 3% of its GDP to energy investment, of which a large share goes to funding clean energy. External finance to India, though, has been inconsistent. Additionally, the dominant sources of funds, namely loans and other official flows (from partner nations), are not scalable. Scalable asset classes like equity investments and private development finance account for a small share in India's renewable energy basket. For example, for the U.S., the U.K. and Germany, equity comprises 80% of their renewable energy finances. To achieve carbon neutrality, besides capacity addition, India needs access to finance that is scalable and self-sustainable.

Foreign investments in Indian renewable energy

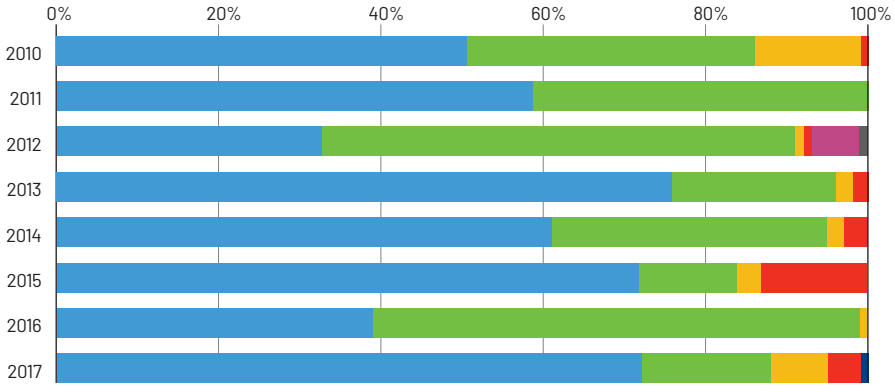
Foreign investments in Indian renewable energy between 2000 and 2017 ($ million)



Source: International Renewable Energy Agency

External financing for Indian renewable energy by source

Share of source of financing (%)



Loans | Other official flows (non-export credit) | Grants | Equity investments | Guarantees | Insurance | Private development finance

Source: International Renewable Energy Agency

While the sun shines...

For India to realise its solar power ambitions, it must rethink issues across the grid – from pricing to regulation to innovation.

Solar power, specifically photovoltaic (PV) energy, is the cheapest solution for new builds in most countries. India has aggressive solar ambitions, aiming to raise solar generation to 100 GW by 2022 and 280 GW by 2030, but in 2021, we are still less than halfway there. The challenge isn't simply in finding funds to build capacity, but in figuring out other issues. Where does solar fit in our portfolio? What are the employment and import implications? What does this mean for consumers? Until we plan these, we may coast along a global price curve and buy ourselves a few years of growth, but we risk facing a wall in the mid-2020s when we can no longer absorb intermittent or variable RE: solar without storage.

Let's work backwards. Who wants solar? Solar is installed at two levels. First, we have grid-scale builds where the buyer is the distribution company (discom) or utility. Alternatively, an end-user like a factory or a household may set up solar if the economics seem attractive.

THE PRICE SIGNAL

One challenge is that we don't price or otherwise signal for electricity by characteristics like time of day (ToD). For decades, India faced power shortages, and "more" was the answer to all problems. Now, we are no longer in deficit in generation capacity, but must meet demand at all periods – and at the right price. If the grid peaks in the evening, when solar output is zero, adding new solar capacity doesn't help. However, adding a new coal plant as a peaker isn't optimal either.

For most end-users, the economics are attractive only because they compare solar power cost (generation) with the retail price, which includes the costs of distribution (last-mile connectivity) plus redundancy. It's not an apples-to-apples comparison. Plus, consumer pricing is skewed: larger homes and commercial/industrial users pay higher rates, and cross-subsidise others. This skews incentives, and begs the question: why do we have 30% capital subsidies for homes? It's the rich who typically install solar systems.

Most end-users will not disconnect from the grid when they add solar; storage is too expensive today. In fact, they will get back on the grid in the evening, when demand peaks. Today's pricing schemes don't reflect this. States are grappling with how to price surplus solar coming from homes or shops at mid-day, when demand is low. Under 'net metering', feeds to the grid were priced the same as the retail tariff, but this doesn't scale for the rest of the system. Now, there are moves to lower solar feed-in prices, but these will reduce the attractiveness of solar power. However, for the utility, this makes sense: if it wanted to encourage solar, it can get a solar farm at around ₹2/kWh, while the retail price for bigger users might be ₹8-10/kWh.

RAHUL TONGIA

Dr Rahul Tongia is a Senior Fellow with the Centre for Social and Economic Progress (CSEP).

@DrTongia

We need a revamp of the entire power system to give retail consumers an incentive to change their consumption patterns.

At a grid scale, the challenges are higher. In the short run, we can absorb solar without storage, by lowering output from the existing (mostly coal) plants, but there is a limit to this. We've pushed up system-level costs elsewhere. But the reality remains: as the share of RE rises, its marginal value declines and its marginal cost of integration rises. ToD issues will become critical just as we begin to exhaust our surplus generation capacity, and need to meet peak demand.

We're also importing most of our solar cells, especially from China. The government supports domestic manufacturing, but there's another consideration. The coal sector provides tens of millions of jobs. With solar, beyond manufacturing, employment is typically at the low-end, for maintenance.

360-DEGREE INNOVATION

India has had limited success in R&D, more so with large-scale manufacturing. We need to innovate for volume, but we also need more fundamental R&D for technologies that are cost-effective and better suited for Indian climatic conditions. Panels must be easier to install and maintain, with integrated designs. For starters, garages and parking spots should design for not just rooftop PV, but proper electric vehicles (EV) connections.

Innovation isn't just about new technology: it's needed across the ecosystem, including regulatory and business models. We need a revamp of the power system, including the pricing mechanism, to give retail consumers an incentive to change their consumption patterns. Someday soon, mid-day electricity may become dirt cheap, when the sun shines bright. How much can we shift our loads, especially cooling, to this period, perhaps also with pre-cooling and thermal storage solutions? With smart meters and smart appliances, we can also shift other loads. Lastly, EVs represent another challenge: if we charge them overnight, the swing producer will not be solar, but coal.

Technology like edge-based solutions, storage, peer-to-peer supply, EVs, and digitalisation can unleash a brave new world, where consumers can become producers, and where 'smarts' has a value, for the end-user and the system. To reach the potential, we must stop treating electricity like a gross commodity or a fruit basket, valued in ₹/kg or ₹/kWh. Just as there are mangos, bananas, lychees, and so on, this 'basket' includes different fuels with different characteristics and prices. Solar is critical, but it cannot operate only with a supply-side lens. We eventually need to move towards a services model, with a focus on quality and safety, and provide an incentive to save energy, not just build more solar panels. •

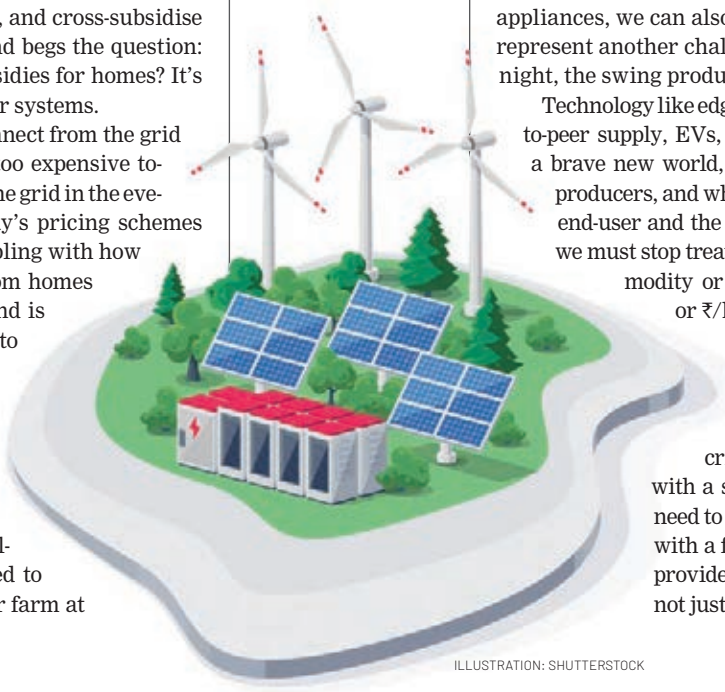


ILLUSTRATION: SHUTTERSTOCK

At a climate crossroads

ILLUSTRATION: SHUTTERSTOCK

Ahead of the upcoming IPCC report, 'hellfire and high-water' images around the world amplify the urgency of climate action.

T.V. PADMA

If the world needed reminders of the grim consequences of 'climate inaction', 2021 has provided them in ample measure. Scorching heat waves across the Pacific Northwest pushed temperatures in Canada and the U.S. to a record 50° Celsius; and intense flooding in Belgium, Germany and the U.K., in Zhengzhou in China's Henan province, and nearer home in parts of Maharashtra and Himachal Pradesh made for apocalyptic images. Taken together, they validate U.N. Secretary-General António Guterres' warning in April that 2021 would perhaps be the "make or break" year to commit to action to avoid all-round devastation induced by climate change.

The world's leading climate scientists began discussions in late July to approve the next report on the physical science basis of climate change – the first of three reports of the Intergovernmental Panel on Climate Change (IPCC's) Sixth Assessment Report. In the run-up to the August 9 release of the report, the central issues had been framed in stark fashion.

A May 2021 report of the World Meteorological Organization noted that there was a 40% chance that the annual average global temperature would reach 1.5°C above the pre-industrial level in at least one of the next five years. In 2020, one of the three warmest years on record, the global average temperature was 1.2°C above the pre-industrial baseline. WMO data also established that the past two decades have seen 18 of the 20 warmest years since record-keeping began in 1850.

And an analysis of the heat waves in North America, by the World Weather Attribution (WWA) Initiative, warned that in a future scenario of a "world with 2°C of global warming" –which at current emission levels would be reached as early as the 2040s – such hellfire events would occur every 5 to 10 years, rather than the current estimates of once every 1,000 years.

The outlook for India too is no less alarming. A national climate change assessment report, released in 2020 by the Ministry of Earth Sciences, projects the average temperature across India to rise by the end of the century by about 4.4°C over the 1976-2005 average in the absence of action, the worst-case scenario. This could increase the frequency of heat waves, severe droughts and cyclonic storms, and of floods in the Himalayan river basins, it warned.

All this calls into question countries' commitment to implementing the 2015 Paris Agreement, which pledged to cap the global rise in temperatures at 2°C, and preferably 1.5°C, compared to pre-industrial levels by the end of the century.

Low-carbon technology may hold the key to decisive climate action, but rich countries hold a disproportionate share of the patents.

As United Nations Framework Convention on Climate Change (UNFCCC) Executive Secretary Patricia Espinosa noted, the world is at a "climate crossroads": it can still limit global warming to 1.5°C by taking appropriate decisions this year, or continue in the opposite direction, which could see a 3°C rise.

For greenhouse gas emissions to be reduced by that magnitude would require an overturning of the current dependence on fossil fuels for energy, a rapid phasing out of fossil fuels and adoption of renewable energy. There is, however, little evidence of political will for such a drastic transformation, given some countries' continued excessive reliance on coal as the primary source of energy. According to a February 2021 UNFCCC report, to achieve the 1.5°C goal, global net anthropogenic carbon dioxide emissions must decline by about 45% from their 2010 levels by 2030, reaching net zero around 2050. And to limit global warming to below 2°C, carbon dioxide emissions need to decrease by about 25% from the 2010 level by 2030 and reach net zero around 2070. Countries are lagging way behind these targets.

Technology may well hold the key to a transformation. There is no dearth of low-carbon technologies (LCTs): 2,464 LCT patents were issued between 2005 and 2015, up 316% over the 1990-2000 period. "For much of the past three decades, the growth rate for LCT patents has been double the growth rate of *all* technology patents," points out Marcello Estevão, Global Director, Macroeconomics, Trade and Investment, The World Bank Group.

In theory, with LCTs becoming cheaper, if they are deployed in just four sectors – energy, transport, industry and buildings – the Paris Agreement goals can be achieved. But there's a snag: rich countries account for a disproportionate share of LCT patents, and the pace of technology transfer to developing countries – which could account for 90% of future carbon emissions – is abysmal. "The technology to power a low-carbon future is available," notes Estevão. "But unless it is transferred *en masse* to developing countries, it's unlikely the Paris Agreement targets for reducing emissions will ever be achieved."

If there's one thing that the recent 'hellfire and high-water' images from various parts of the world have established, it is that humanity can no longer afford to delay strong action. There is a fierce urgency to the need for climate action. •

Jyothi's wheelchair was too big and unconvenient for her to push around. Its uncomfortable frame did not fit her well and caused pain in her shoulders.
She could barely use her wheelchair on the road.

So she decided to do something about it.

And then she discovered NeoMotion

After having her measurements taken, an order was placed

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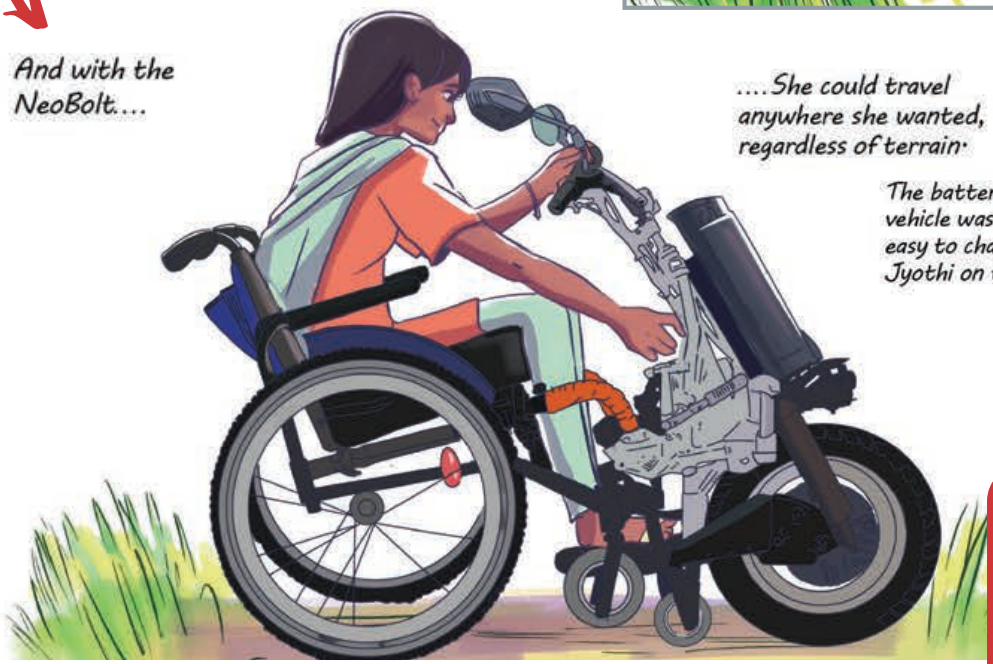
At last, Jyothi had a wheelchair that was compact, convenient, and perfectly customised to fit her needs

Jyothi was finally independant and could go anywhere, anytime.

And with the NeoBolt....



....She could travel anywhere she wanted, regardless of terrain.

The battery powered vehicle was cost effective, easy to charge, and kept Jyothi on the go.

The easy to attach frame converted her wheelchair into a fully functional electric scooter within 10 seconds

NEOMOTION
LIVE LIFE TO THE FULLEST

Up in the air to conduct experiments on monsoon clouds, IITM scientists Thara Prabhakaran (*right*) and Neelam Malap. A better understanding of cloud formation and behaviour is expected to help make more accurate forecasts.

PHOTO: BY SPECIAL ARRANGEMENT

It's raining weather models!

Scientists at the Indian Institute of Tropical Meteorology are using better data sets, and a deeper understanding of atmospheric processes, to improve weather and climate forecasting.

MYWISH ANAND

Cumulonimbus clouds, multilayered and extending high up into the atmosphere, weave beautiful patterns in the sky but pose serious danger to aircraft. They can shake up a plane flying through them, cause damage to communication systems, and make the pilots feel disoriented. Aircraft inside such clouds can spin out of control when the turbulence becomes severe. Occasionally, when tornadoes are lurking around, the aircraft can even break into pieces. Pilots avoid such clouds, often staying as far as 40 kilometres away from them.

At the Indian Institute of Tropical Meteorology (IITM) in Pune, Thara Prabhakaran and her colleagues hire planes and fly above, below – and even right into – the cumulonimbus clouds in the early stages of formation. Specially trained pilots fly the Beechcraft B200 aircraft, which has scientific instruments on the wings and inlets to get the air through another set of instruments in the cabin. The pilot and the passengers, however, must bear the discomfort and the risk. The aircraft shudders vigorously when it enters the clouds, bobbing up and down severely when hit by updrafts and downdrafts. When the aircraft is not pressurised, as was the case in some of her early missions, the eardrums of the passengers ache, and their head seems to spin.

During her flights, Thara Prabhakaran measures the size, number and other aspects of particles in various clouds. Her aim is to predict whether or not a cloud will precipitate as rain.

Most of Prabhakaran's air missions are to study cloud seeding, but she uses the opportunity also to understand cloud formation and behaviour. Among other things, she is looking to figure out how aerosol particles in the clouds influence the weather. Aerosols can act as condensation nuclei, which are small particles on which vapour condenses to form water or ice. No one understands precisely how these processes work. Clouds, in general, are a poorly understood phenomenon, but they have a significant influence on weather and climate. "We are only beginning our studies," says Prabhakaran.

Prabhakaran's work is part of a series of research projects at IITM to understand the physics of the world around us, and to use this understanding to improve forecasting of weather and climate. More than ten years ago, when such efforts began at IITM, monsoon weather forecasting in India was based largely on empirical observations and statistical models. Such forecasts were famously inaccurate,

as we would expect from models that did not incorporate enough atmospheric physics, apart from suffering from paucity of data and inadequate computational power. While data collection and computational facilities have improved over the past few years, scientists are far from fully understanding the processes that drive weather and climate. "Prescription of physical processes into the models is one of the weakest links in weather forecasting," says IITM Director Ravi S. Nanjundiah.

IITM had begun monsoon modelling as a small project more than a decade ago. At that time, the India Meteorological Department (IMD) used to give forecasts based on its own models that were partly statistical and partly dynamical. Land, Atmosphere and Ocean models were all worked out separately but not integrated. Incorporating the interwoven dynamics of the three ecosystems was a necessary step in building good prediction models.

As IITM began this work and its models improved, the IMD began slowly replacing parts of its models with those of the Pune-based institute. The National Monsoon Mission gave a fillip to model-building in the country by funding research and creating high-performance computing facilities, apart from collecting more data. Till 2017, IITM gathered data from square grids, each a side of 37.5 kilometres. With improved computing facilities, this has shrunk to roughly 12 kilometres, a very high resolution for short-range forecasts when compared to those from other institutions.

High-resolution models alone do not guarantee good forecasts unless they are backed by sound data and a deep understanding of the physical and biological processes that drive weather and climate. Data collection has been sparse over India, especially over the oceans on either side of the subcontinent, but it has improved in the past few years. And although many atmospheric processes are still not well-understood, research projects are providing hints into the possibilities for forecasting over the next decade.

For example, the Bay of Bengal is a key player in the development and subsequent behaviour of the monsoon. This area of the ocean has peculiar characteristics due to the large amounts of fresh water flowing from the Ganga and the Brahmaputra. This fresh water pushes the salt water in the ocean back, causing the formation of steep salinity gradient layers in the Bay of Bengal. Since salt water heats up faster than fresh water, the salinity gradient creates a steep temperature gradient on the sea surface. In the long run, it raises the ocean's temperature and gives rise to a multitude of weather fronts in the Bay of Bengal. These weather fronts are the reason the Bay of Bengal fosters more cyclonic activities than the Arabian Sea does.

Older models did not integrate such observations from the ocean and the atmosphere. Suryachandra A. Rao, professor at IITM, brought them into the model by mapping the winds and circulation over the Indian Ocean and the Indian subcontinent using the data from satellites and instruments set up in the oceans. The recent discovery of the stratified structure of the Bay of Bengal and its mixing processes are now integrated into the models.

For a long time, Rao had been researching ocean-atmosphere coupling, an interaction that initiates the Indian summer monsoon and cyclones. Rao and his colleagues built systems that connect and refine the collected data before being sent as an input in the model, systems that capture the rich physics in the interplay between the ocean and the atmosphere. They are used to derive empirical laws – those derived from observation – for the physical parameters that are not well-understood and defined in the model. Convection is one such parameter derived from the ocean-atmosphere interplay. Cloud microphysics is another, with its empirical relations derived from flight observations and experiments. "This coupled-data assimilation technique has improved our forecasts by providing error-minimised data for the model," says Rao.

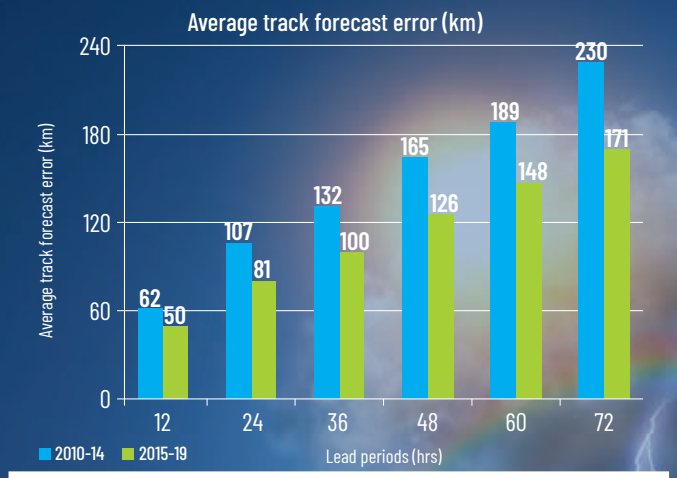
IITM professor Suryachandra A. Rao incorporated observations from the ocean and the atmosphere into weather models by mapping the winds and circulation over the Indian Ocean and the Indian subcontinent.

PHOTO: BY SPECIAL ARRANGEMENT

Suryachandra Rao and his colleagues have built systems that capture the rich physics in the interplay between the ocean and the atmosphere.

The forecasts are getting better

Over the past decade, IMD's record of average operational tropical cyclone track forecast, as reflected in two key metrices, improved significantly relative to climatology and persistence (CLIPER) forecast



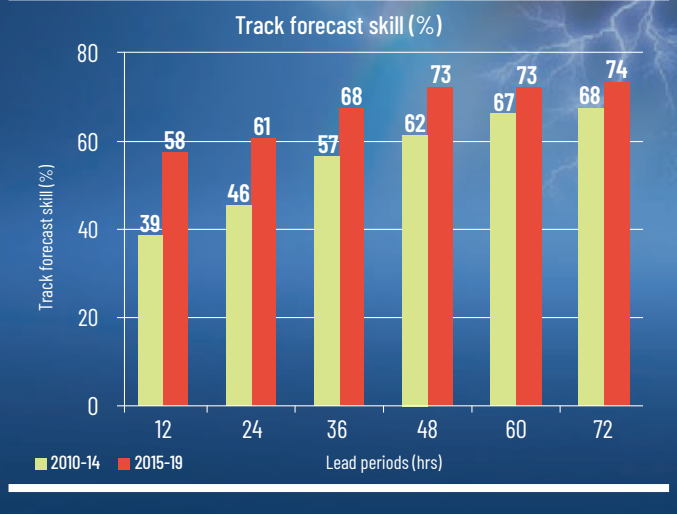


PHOTO: BY SPECIAL ARRANGEMENT

Climate scientist Roxy Mathew Koll employs an earth system model, developed by IITM to study the warming of the Indian Ocean, to predict the climate on the Indian subcontinent till the end of the century.

A better understanding of cloud formation is expected to create a significant impact on forecasts. In fact, lack of real knowledge of cloud physics has for long been one of the serious shortfalls of weather models. Although empirical laws are now incorporated into the models, it is hard to give long-range forecasts without understanding cloud physics. A key player in this physics is aerosols, small particles that are emitted from the earth's surface and linger in the air for a long time.

Aerosols play a significant role in the formation and evolution of cumulonimbus clouds. They are all around us, both near the surface and high up in the atmosphere. Some aerosols are natural in origin: sea salts, dust, volcanic ash, carbon from forest fires. Human-made aerosols are exhausts from automobiles and power plants, cigarette smoke, smoke from cooking stoves and so on. About 90% of the aerosols are natural in origin. However, human-made – or anthropogenic – aerosols are increasing in volumes. Since they are also concentrated in a small region, like cities, anthropogenic aerosols may have a disproportionate influence on the weather – and, by extension, on the climate.

During her flights, Prabhakaran measures the size, number and other aspects of particles in various clouds. Her aim is to predict whether or not a cloud will precipitate as rain, and how the location of the cloud affects its precipitation. From her flights, she found a direct impact of pollution on cloud physics at a micro level. Clouds formed in a polluted region have a greater number of particles and tend to live longer than the clouds formed in a clean environment. Since the water content of clouds is a constant quantity, clouds with fewer particles form larger droplets and thereby result in rains earlier than clouds with a large number of particles. Since clouds reflect solar radiation back into space, polluted clouds reduce the solar radiation reaching the earth's surface by remaining in the atmosphere longer than those with fewer aerosols. They finally produce rains at much higher altitudes than the conventional clouds formed in clean environments.

Prabhakaran also works on nimbostratus clouds, dark grey clouds that bring heavy rainfall. Nimbostratus clouds contain both warm rain droplets and ice particles. Such a mixed phase is directly associated with extreme rainfall and thunderstorm events, but their physics is not incorporated in the models. Such events are increasing in number due to climate change, but scientists cannot predict them well enough due to a lack of understanding and data.

Prabhakaran's team observed an ice-splintering mechanism in the nimbostratus clouds, where bigger drops at colder temperatures start freezing suddenly, followed by their breaking apart. This results in the formation of too many ice particles, thereby leading to heavy snow and rain upon melting. Such a mechanism had not been noticed before her observations during flights.

There are many other important cloud phenomena that are not understood. For example, clouds in the Himalayas form at temperatures ranging from -3° Celsius to -40° Celsius. Their ice nuclei particles grow, decay and precipitate below freezing point. When the precipitation reaches clouds below them, at warmer temperatures, they melt and cause the other clouds as well to precipitate. This process is not incorporated in the model yet.

As meteorologists begin to understand weather better, they start extending their computations for longer and longer periods to see what lies in the future as climate. An improved understanding of the physics of weather helps improve climate models as well, and IITM had tweaked the weather models to be relevant for studying long-term climate change as well. Specifically, good climate models need inputs on the relationship between the oceans and the atmosphere and the land. And there is an additional aspect of the oceans that is relevant for climate but not for weather prediction: how the biology of the ocean changes with temperature.

Oceans are the heat sinks of the earth, as they absorb more than 93% of the heat generated due to global warming. Warmer oceans tend to expel dissolved oxygen, thereby affecting organisms living in that region. The Indian Ocean has so far warmed by 1.2° Celsius, and is expected to warm up quickly in the future.

Roxy Mathew Koll is also working to understand how phytoplanktons would respond to a warming ocean and their effect on the food chain.

Roxy Mathew Koll uses an earth system model developed by IITM to study the Indian Ocean's warming, and employs this model to predict the climate of the Indian subcontinent till the end of the century. Koll is also working to understand how phytoplanktons in the oceans would interact with the warming water and influence the climate, apart from affecting the food chain. The past six decades have seen a substantial decrease in these phytoplanktons in the Indian Ocean, but no one knows whether this decrease is due to climate change.

The western part of the Indian Ocean has large amounts of fish, and decreasing phytoplanktons and continued Indian Ocean warming might result in this productivity region becoming an ecological desert. "If, at some point in the future, we can incorporate fisheries in the IITM model, that might further improve our understanding of how greenhouse gases and climate change would welcome us in the future," says Koll. As the phytoplanktons are a part of the carbon cycle, their decline may have a feedback loop into climate of the future. But not much research has gone into this aspect.

Investments in the past decade in India have improved the collection of data, computational facilities and the understanding of the earth as a system. And yet, the science of weather and climate has huge gaps that researchers are now addressing. Although it may not be possible to create the weather that we like, accurate prediction can reduce the damage and help us to adapt to climate change. •

In blockchain we trust

The decentralised ledger technology has the capacity to influence transaction costs by building trust, which could transform organisations.

NIRANJAN RAJADHYAKSHA

Niranjan Rajadhyaksha is Research Director and Senior Fellow at IDFC Institute.

The wild swings in the prices of cryptocurrencies such as Bitcoin have dominated much of the public discourse on blockchain. The ability of this new decentralised ledger technology to create digital financial assets that may eventually challenge sovereign currencies is undoubtedly important. Far less attention is lavished on the ability of blockchain to alter existing forms of economic organisations. To understand this better, we need to rewind to a landmark paper written many decades ago.

British economist Ronald Coase asked a simple question in 1937: Why do firms exist? Most economists till then had sought to explain how economic exchange takes place between buyers and sellers in a market. Coase noted that not all transactions take place the way economics textbooks describe them. Many transactions take place within firms, as when one division of a company provides inputs or services to another division in the same company. Coase showed that firms exist to minimise transaction costs.

American economist Oliver Williamson took this insight further in a 1985 paper to ask: under what conditions does economic exchange take place within organisations rather than in markets? The fundamental idea was that there are transaction costs involved in all economic exchanges. Firms decide which activities to conduct within their boundaries and which to conduct in the market based on the transaction costs. The higher the transaction costs of a market exchange, the higher the likelihood of certain activities being done within the firm. Coase won the economics Nobel in 1991; Williamson won it in 2009.

However, transaction costs are not static. Therefore, the boundaries of firms change depending on how transaction costs change. Vertically integrated companies have given way to global supply chains, thanks to the collapse in the costs of computer networks. Companies can now participate in complex production networks coordinated through enterprise software rather than from an integrated corporate headquarters: virtual integration rather than vertical integration.

TRUST MATTERS

The global production process has become more efficient even as it has become more decentralised. Is another revolution in industrial organisation on the horizon with the rise of blockchain? The decentralised ledger technology deals with another aspect of economic organisation — trust, which is a key determinant of transaction costs.

It is relatively easy to establish trust between two people who know each other. A local vegetable seller is unlikely to cheat a regular customer who visits him every day. However, trust becomes complicated when the economic exchange is between two people or companies that do not know each other, and even more so when they carry out a one-time exchange in the spot market rather than enter into long-term contracts.

Digital companies have already found some solutions that build trust. Online companies such as Airbnb have a system of user ratings to provide information to new users about the reliability of a person temporarily renting out her flat or of a person who seeks to stay in it for a short holiday. This crowdsourced system of ratings builds trust into the transaction. A tourist who would earlier only be comfortable staying in a hotel chain — brands signal trustworthiness — can now pay money upfront to use the flat of someone she has never met before and will likely never meet again.

Blockchain uses a distributed ledger to do something similar. In his famous paper that explained the idea of Bitcoins to the world, Satoshi Nakamoto said he was proposing a system of electronic transactions without relying on trust. What he meant was that trust emerges not from the people who are transacting or from an intermediary, but from the structure of the network itself: each person in the network can check the validity of a transaction.

PHOTO: SHUTTERSTOCK

With blockchain technology, trust emerges not from the people who are transacting or from an intermediary, but from the structure of the network itself.

"Blockchains create trust by acting as a shared database, distributed across vast peer-to-peer networks that have no single point of failure and no single source of truth, implying that no individual entity can own a blockchain network, and no single entity can modify the data stored on it unilaterally without the consensus of its peers," says the policy planning thinktank NITI Aayog in a paper on how the new technology can be applied in India.

A BLOCKCHAIN DISRUPTION

Blockchain can open up new possibilities thanks to the way it builds trust through its very structure. The future is hazy, but digital evangelists believe that blockchain has the potential to rearrange the way we work within economic organisations as well as how we transact in the market. If the fall in the price of computer hardware, the ubiquity of enterprise software and the resulting decline in transaction costs helped replace vertically integrated companies with virtually integrated supply chains, then blockchain can change the internal structure of companies through its cooperative structure.

Some of the most radical possibilities are the replacement of top-down managerial structures with flat organisations where workers collaborate through some form of blockchain. The result could either be re-engineered companies or even a new form of organisation akin to digital cooperatives.

The questions that institutional economists such as Coase and Williamson asked many decades ago can still inform some of the emerging debates on the impact of blockchain on economic organisations. •

ILLUSTRATION: SHUTTERSTOCK

Fighting an infodemic

The disinformation epidemic is as virulent as COVID, and just as lethal. But technology can help keep public platforms safe.

JAYADEVAN P.K.

In August 2020, when COVID-19 was raging across the world, World Health Organization Director-General Tedros Adhanom Ghebreyesus raised an additional red flag. "We're not just battling the virus," he said. "We're also battling the trolls and conspiracy theorists that push misinformation and undermine the outbreak response." An 'infodemic' — an information epidemic — was feeding into anti-vaccine sentiments and pushing people to take unsafe steps in the hopes of a cure, the agency noted. In Iran, nearly 700 people died after drinking toxic methanol based on social media claims that it could kill the virus. "This is the kind of dangerous misinformation that WHO is most worried about," the organisation said.

Infodemics spread even in 'normal' times. In 2017, there were several instances of lynchings in Jharkhand: vigilante mobs, triggered by WhatsApp rumours of children being kidnapped, had set upon suspected 'child-lifters'. Over 20 people were killed, and over 600 arrested.

Some 11,000 km away from India's heartland, in Pennsylvania, S. Shyam Sundar read reports of these lynchings in horror. As a doctoral student at Stanford in the 2000s, he had studied the impact of the internet on media and society, but for the first time in years, he was watching misinformation risk lives. "It was mostly an academic pursuit in the 1990s, but now fake news and misinformation have devastating real-world impact," he told this writer.

By most accounts, the battle against the infodemic is proving arduous. But technologists and organisations are coming together to combat the infodemic, and early results are promising. "The only way to deal with this infodemic at scale is to build guardrails with technology," says Sundar, founding director of the Media Effects Research Laboratory at Penn State University's College of Communications.

The roots of the 'fake news' problem run deep. Even before the internet era, misinformation and fake news were used to sabotage political opponents. In the 1970s, investigative journalists Bob Woodward and Carl Bernstein made public the political 'dirty tricks', including active disinformation, at play in the Watergate scandal. News (including fake news) did not travel as fast in those times; even when the internet became mainstream, fake news spread mostly on email. Websites that countered

misinformation were good enough for the time. Email providers also got better at fighting spam. But with cheap data, smartphones and social media in the hands of billions of users, the speed and scale at which fake news travels and snowballs into a bigger problem have accelerated.

The year 2016 was a tipping point. A BuzzFeed News analysis noted that leading up to the U.S. Presidential elections that year, fake election news had more engagement on Facebook than election stories from 19 top news outlets taken together. "This made people sit up and take note of the fake-news phenomenon," says Sundar. Several hyper-partisan pages on Facebook and more than 100 U.S. politics websites that operated out of Macedonia, in the Balkans, published false or misleading content at an "alarming rate". Underemployed Macedonian teenagers were making a quick buck by driving traffic to their fake-news sites.

Subsequent investigations established that fake news was being used by several agencies, including foreign ones, to undermine democracy. "This became an international phenomenon. It's a big issue in India as well, and extends beyond politics," says Sundar. The internet has made it possible for anonymous users in one part of the world to influence millions of others elsewhere.

TECHNOLOGY & SOLUTIONS

When companies like Facebook, Twitter and Google were held responsible for amplifying the infodemic, they took several remedial measures. The most important one was to create a network of third-party fact-checkers and content moderators who could verify stories and help flag them. Several such initiatives have mushroomed across the world. Some are independent; some are funded by platforms. The International Fact-Checking Network (IFCN) was set up by the Poynter Institute in September 2015 to support fact-checking initiatives by promoting best practices. India has more than a dozen fact-checking outfits, including BOOM, WebQoof, THIP Media and Alt News.

"At present, technology can only be assistive and not proactive," says Rajneil Kamath, co-founder of Newschecker, an independent fact-check initiative that's part of the IFCN. "Many of our processes and tasks are being automated," says Kamath, whose company fact-checks news in nine Indian languages.

However, not only is human fact-checking and content moderation hard to scale, it also takes a toll on people. Workers hired to moderate content on platforms develop psychological problems from prolonged exposure to harmful content. Between third-party fact-checkers and outsourced content moderators, only a fraction of the content online is checked. "By the time it's fact-checked, the damage is already done," says Sundar.

To slow the velocity of misinformation and fake news, platforms have also built product features. WhatsApp, for instance, introduced a limit on forwarding viral messages. Twitter prompts its users to read an article before it's reshared on the platform. This has had some impact: Twitter learnt that people access articles 40% more often after seeing the prompt. But the volume of fake and misleading information is still high.

This meant that platforms lean more and more towards technology that helps look for and flag tell-tale signs of fake or misleading information. The signs could be the way sentences are structured, the source of information, and dozens of other factors. Even so, fake stories spread, and organisations have to take proactive measures to curb misinformation. WHO's response is a good example of such an approach. It worked with nearly 50 tech companies, including TikTok, Google, WhatsApp and YouTube to prompt warnings and prioritise information from official sources to users. Over 1 billion people were steered towards COVID-related resources from health authorities after seeing Facebook prompts, the company said in March.

WHO also partnered with an analytics company, which reviews nearly 1.6 million pieces of information on various platforms and uses machine learning to glean insights into what users are searching for and comes up with tailored messages. It also collaborated with the U.N. Global Pulse Initiative to listen to radio news in some countries, and used speech recognition to identify and address concerns.

At the other end, researchers like Sundar are beginning to understand the problem better. His proposal to examine the Jharkhand lynchings was funded by WhatsApp, which set aside $1 million to fund research across five areas, including information processing of problematic content; digital literacy and misinformation; election-related misinformation; network effects and virality. The project, titled 'Seeing is believing', found that videos were considered more believable. In 2019, Sundar's team tested the hypothesis by stripping down the story into audio-only, and into text-only. The messages were shown on WhatsApp to 180 participants in Delhi and Bihar split across urban and rural areas. The study found that people who don't know much about a topic are more likely to fall for the "video effect".

Dr S. Shyam Sundar, founding director of the Media Effects Research Laboratory at Penn State University's College of Communications.

"The only way to deal with infodemics at scale is to build guardrails with technology," reckons S. Shyam Sundar.

"Video fake stories are more pernicious because they seem to make people believe they have seen it," says Sundar. The team recommended that platforms prioritise action against video fakes. This, of course, throws up newer challenges because synthetic videos are also growing at an exponential rate. The growth is driven in part by the use of artificial intelligence techniques to generate so-called 'deep fake' videos – "fake" videos created using "deep" learning.

"It is a recipe to generate fake news at scale. And scale makes it harder to deal with," says Dr Sundeep Teki, who has worked on artificial intelligence problems at Amazon Alexa and Swiggy.

While public platforms like Twitter and Facebook are able to see the content and take action on it, platforms like WhatsApp are constrained by their encryption commitment and the expectation of privacy of communication. One way to intervene is

to base their actions on meta tags, which can tell videos from text. Flagged videos can be marked for more active investigation and study.

AI vs FAKE NEWS

The most promising way to deal with the infodemic at scale is the use of artificial intelligence and machine learning. The idea is to label stories and users as fake or real or flag them for human investigation using machine learning models. Researchers concur that differentiating between a real and a fake story is a fairly contained problem. But once a story is identified as fake, the job gets harder. 'Stories' can be political commentary, satire, opinions, native advertisements and so on. It is hard to differentiate between satire and patently false information with intent to harm, and between native advertising and opinion pieces.

Techniques such as supervised learning algorithms that are built for English can be scaled to other languages (even if some nuances are missed) by taking a corpus of material and training the models using new data. For example, a big part of an ongoing project at Facebook identifies the language in which the content is created. The project, funded by a Social Media and Democracy Research Grant, awarded by The Social Science Research Council, will let researchers see the websites that users have shared, unique characteristics of the URLs, and some demographic information about users.

THE DATASET CHALLENGE

While fake-news models can be applied to nearly every language, platforms may not drive these initiatives due to market considerations. This is where the work of experts like Teki becomes important. Teki has worked in four countries at the intersection of artificial intelligence and neuroscience. He was also a Wellcome Trust Fellow in Neuroscience at Oxford University and obtained his PhD from University College London. Along with student collaborators, he recently published two papers focussed on COVID-19 fake-news detection and hostility detection in Devanagari (Hindi) Tweets at the 'NLP for Internet Freedom Workshop', COLING'2020, and 'Combating Online Hostile Posts in Regional Languages during Emergency Situation', AAAI 2021.

"Sophisticated deep learning models can be used to detect fake news and fact-check for emerging topics like COVID-19," Teki says.

Artificial intelligence models use large amounts of publicly available text (like Wikipedia) to train established 'language' models such as GPT-3, BERT or ALBERT. As these models process more data specific to a problem, they learn to better understand the relationship between words and the context of their use. For instance, Bidirectional Encoder Representations from Transformers (BERT) is a natural language processing (NLP) model developed by Google in 2018. It was mainly used to understand user searches and was a landmark breakthrough in NLP. Compared to previous language models, BERT demonstrated state-of-the-art performance on a variety of natural language understanding tasks by capturing more sophisticated contextual relationships between words. If you say: "There's a coronavirus lockdown in Bengaluru," the model understands that Bengaluru is a city, coronavirus is a pandemic, and so on. These models serve as a proxy for a language, to better capture the meaning and the context. "The holy grail for work on language models is to improve their contextual understanding of words and sentences to the same level as humans, and eventually surpass human benchmarks," says Teki.

Dr Sundeep Teki has worked in four countries at the intersection of artificial intelligence and neuroscience.

"Deep learning models can be used to detect fake news and fact-check for emerging topics like COVID-19," says Dr Sundeep Teki.

Once the researchers zeroed in on a language model, they applied a technique called transfer learning. The idea was to parse through thousands of new sentences particular to COVID-19 and get a better understanding of those sentences. "Once we have a piece of text in a vectorial form (embedding) it is easy to do all kinds of mathematical, machine learning approaches to understand and predict various aspects of language, including intent, sentiment, entities, comprehension, and so on," Teki explains. More than nine times out of 10, the model could identify whether a Tweet was fake or not. The models get better with more powerful algorithms and better-quality data. Several fake-news detection datasets are available on Github, but these are mostly focussed on the U.S. and Europe. Manually curating such datasets is difficult and prone to errors: ImageNet, the most popular image recognition dataset, was built over 4-5 years. "We don't have robust data sets like ImageNet for fake news yet," says Teki.

OPEN DATA AND RESEARCH

With platforms opening up data for researchers, things might improve in the future. For instance, over 100 researchers and developer teams were granted access to the COVID-19 data stream by Twitter. More than half of them focussed on disinformation and misinformation around the coronavirus. Open data from platforms can also throw up interesting findings that help combat the infodemic. By using data from Twitter and artificial intelligence techniques, researchers from Georgia Institute of Technology and New York University created a novel dataset of 155,468 COVID-19-related tweets, containing 33,237 false claims and 33,413 refuting arguments. Their findings, published in November 2020, yielded an important insight: to effectively study misinformation, one needs to tap into the wisdom of the crowds "because 96% of all refutations are being done by concerned citizens (i.e., the crowd)." The "crowd" often counters misinformation with links to fact-checks or other trusted sources. Opinion-based tweets were more assertive, used more negative words, were more abusive, and exhibited negative emotions and anger, the study found. The analysis can potentially lead to the development of better tools and an understanding of approaches that use the crowd to counter misinformation.

While these are promising approaches, technology alone can't solve the infodemic in its entirety. It will need a multidisciplinary approach with researchers, policymakers, platforms and technologists coming together. •

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The pulse of a farm revolution

For years, Rajeev Varshney has been using genome-assisted breeding techniques to create hardy crops. Now, he is leveraging AI in the cause of crop improvement.

ADITI JAIN

As an agricultural scientist, Rajeev Varshney was only too aware, back in 2005-2007, that just as with plants, it takes time for ideas to germinate, grow, blossom – and finally come to fruition. That time period cannot be abridged because nature cannot be rushed. Despite that awareness, he struggled to come to terms with the fact that the ambitious research project he had embarked upon, inspired by a speech in 2003 by Norman Borlaug, the Father of Green Revolution, had failed to take root.

Dr Rajeev Varshney in a chickpea field. Using genome-assisted breeding approaches, his team has developed hardy varieties of chickpea, including a drought-resistant variety.

PHOTO: BY SPECIAL ARRANGEMENT

That research, at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad, was centred around ushering in a second farm revolution – in pulses and oilseed production – by developing better-yielding crops in the same way that the Green Revolution in India had rendered the country self-sufficient in wheat and rice production.

The Borlaug speech that was to alter the course of his life was delivered at the University of Bologna, Italy. Varshney, then a research scientist at the Leibniz Institute of Plant Genetics and Crop Plant Research, at Gatersleben (in central Germany), was attending a conference in Bologna. There, Borlaug challenged the next generation of scientists to harness the power of genomics and biotechnology to usher in the next revolution in agriculture.

"The conference was a turning point in my career," says Varshney, who is today ICRISAT's Research Program Director – Accelerated Crop Improvement Programme. "I decided to give up the basic research project I was pursuing in Germany and return to India and use the power of gene technology to create better crops for farmers in my country."

Thus inspired, Varshney started his laboratory work at ICRISAT with a lofty mission: to bring prosperity into the lives of small-holder farmers, particularly in central and southern India, who had not quite been enriched by the Green Revolution. The fertile fields in the northern Indian States of Punjab, Haryana and Uttar Pradesh, and the farmers who worked on them, had benefited from the high-yield varieties of wheat and rice of that revolution. But the nutrient-deficient soil and rainfed lands in the semi-arid regions in central and southern India were unable to support these better-yielding wheat and rice crops.

Varshney reckoned that developing better-yielding pulses and oilseeds using genome-assisted breeding techniques would not only enhance the income of small-holder farmers, but ensure the country's nutritional security by putting the semi-arid stretch of land to productive use.

The idea was lofty, but the road was tough.

SMALL POOL

"For two years from 2005, I struggled in my research career," recalls Varshney. "There was only limited genetic information on the crops I chose to work on" – chickpea (Indian chana), pigeon pea and groundnut. He looked around for collaborators, but very few scientists were working on these crops. He could not secure funding for his project proposals.

Self-doubt began to creep in, like weeds in the fields. "It made me wonder if I had perhaps been unwise to choose to research these crops – and whether I would have been better off working on rice and wheat, considering the wealth of genetic information about them that was available," he recalls.

However, those moments of emotional and professional low soon gave way to clarity of purpose. Varshney reckoned that if he wanted to continue researching these 'orphan crops', he would perhaps have to spend years to build a strong-enough foundation of knowledge of these crops, on which his team could then carry out translational research.

So, the initial years of his team's research went into deciphering primary knowledge about chickpea, pigeon pea and groundnut. As they gathered more knowledge on these plants, the roadblocks to creating better varieties in these crops began to clear, and Varshney's research gathered pace.

Over the years, the institute has collected nearly 20,000 chickpea varieties from various agro-climatic zones around the world, and has created a biobank. With its research expertise, Varshney's team has

generated genome sequence data and phenotypic data (that is, observable characteristics) of 3,000 chickpea lines from this collection. The idea is to use the data from these 3,000 lines as training inputs for machine learning algorithms and then predict the phenotype of the rest of the 20,000 chickpea varieties based on their genomic data. The team has collaborated with three premier research institutes on this project: the International Maize and Wheat Improvement Center (CIMMYT), based in Mexico; The University of Western Australia; and the Skolkovo Institute of Science and Technology (Skoltech), in Russia.

THE TRAIT SEARCH

In traditional plant breeding experiments, the breeder makes a cross between two desirable parents, each carrying a distinct desirable trait. Some of the progeny obtained through this combination is expected to carry both the desirable traits from its parents. However, finding out which offspring carries the desirable traits is time-intensive. It requires scientists to put all the progenies in a large field and wait until they start to display the required traits.

While some traits such as leaf shape manifest themselves earlier in the plant life, breeders are required to wait until the end of the life cycle of the plant in order to observe traits like seed quality. This may vary from a month to several years.

Apart from the element of time, plant breeding is a mammoth exercise. Plants produce a large number of seeds after pollination. This means that scientists have to screen or look out for traits in many individuals so as to not miss the required traits. Moreover, this exercise of screening/looking out for desired traits needs to be carried over several generations in order to stabilise or fix the favourable traits.

Using the genome-assisted breeding approaches that Varshney's lab has used to create better crops, one can screen the progenies even at the plantlet stage – and identify the ones that carry both the desired traits. This is because although plants display their traits at a given time in their life history or under certain given conditions, they have the genes associated with this trait ingrained in their genome throughout their life, which can be screened in the early stages of the plant cycle.

Using this approach, the group has developed a drought-resistant chickpea variety 'Pusa Chickpea 10216', which has an overall mean weighted yield advantage of about 16% as compared to its predecessor. Similarly, the team has developed a chickpea variety that is resistant to fusarium wilt disease named 'Super Annigeri 1', which has a 7% mean yield advantage for farmers over its parent 'Annigeri 1'.

Not only have the drought-resistant chickpea varieties developed by Varshney been tested and are being used in India, but they have also been released in Ethiopia and are being tested in a few other countries. Although these varieties fulfil the promise of better yield, the road to developing these varieties was long and arduous. The seeds of the plants that now stand erect in the field were sown as far back as in 2006!

THE NEXT REVOLUTION

Varshney's lab, in the lush green 3,500-acre ICRISAT campus in Hyderabad, has now been at work for over a decade and a half in order to create better crop varieties. But its methods are increasingly getting more sophisticated, which promises to save both time and labour. His team is harnessing the power of artificial intelligence (AI) to aid plant breeding experiments in their endeavour to create drought-resistant varieties of chickpea. The goals of the program, if realised, will open up avenues for better plant varieties.

"With the advent of large-scale and high-throughput sequencing technologies, we are now able to generate large high-density genome sequencing data and also transcriptome data from various parts of a plant including at single cell level," says Varshney. In his estimation, AI holds enormous promise for plant science. Using remote-sensing and drone technology, scientists can produce phenotypic data as well. Soon, scientists will be able to integrate the genomic sequence data and phenotypic data using AI and machine learning techniques "which will enable us to predict the performance of a line with higher precision and efficiency."

Today, as Varshney stands amidst a field planted with drought-tolerant chickpea and nutrition-rich groundnut bred by his research group, he is overcome by a sense of satisfaction that his mission to return to his homeland and serve the farmer community is closer to being accomplished.

PHOTO: BY SPECIAL ARRANGEMENT

In the lab. Artificial intelligence and machine learning hold big promise for plant science, particularly when integrated with genomic sequence data and phenotypic data.

Listening to a Norman Borlaug lecture at a Bologna conference in 2003 changed the trajectory of Varshney's career: it inspired him to return to India to "create better crops for farmers".

Having harnessed the power of the gene revolution, Varshney is now looking to leverage the power of AI in crop improvement programs. The genome-assisted plant breeding approach rested on a few handfuls of genes, but AI and Big Data sciences will allow the analysis of thousands of genes or whole-plant genomes at one go. This will allow plant breeders to optimise for more than two traits as in the case of genome-assisted breeding.

The challenge that Borlaug set for scientists at that Bologna conference – which Varshney took to heart – has been well and truly joined. Genomics, biotechnology and AI are leading the charge towards the next agricultural revolution. •

Shantanu Chowdhury (*right*) and Ananda Kishore Mukherjee at the Institute of Genomics and Integrative Biology.

PHOTO: TRIBHUWAN SHARMA

Looking beyond the double helix

A recent study provides novel insights into potential therapeutic opportunities to target cancer.

ADITA JOSHI

In 2013, American and German scientists discovered two mutations that occurred in 80% of brain cancers, 71% of skin cancers, and to a lesser degree in bladder and liver cancers. The mutations were in the telomerase enzyme that plays a role in maintaining telomeres – the end regions of chromosomes. The telomere acts like a protective cap of the chromosome, but it becomes shorter and shorter with each cell division. The cell dies when the telomere reaches a certain length, which is a mechanism for old cells to make way for new ones. Cancerous cells, through mutations, seem to hijack this machinery and divide forever.

The findings of that research study, published in *Science* journal, had got the attention of scientists around the world who were working on telomeres. Among them was Shantanu Chowdhury at the Institute of Genomics and Integrative Biology (IGIB) in Delhi. Chowdhury's research centred around the enzyme telomerase, which is necessary in telomere synthesis. How the cell regulates this enzyme is poorly understood; however, scientists know that its production is shut down in normal adult cells but reactivated in cancer cells. Chowdhury and others had been working on the problem.

The mutation discovered in 2013 occurred in a region of DNA that was rich in a chemical base called guanine. The DNA in this guanine-rich region folds into four stacked sheets, which are together called G-quadruplexes (G4). The mutations occurred in the G4 sequence and disrupted its quadruple sheet structure, which somehow led to telomerase-reactivation in some cancers. "This information kept haunting me. I kept thinking about the core mechanism and interesting avenues where we can exploit telomerase-specific G4 for therapeutic benefits," says Chowdhury.

Chowdhury had been interested in G4 since 2002, when he joined IGIB as a young scientist. It was soon after the human genome was sequenced, and technologies had become available to sequence large genomes quickly. His group analysed several genome sequences to discover that G4s occur in promoters – on-off switches – of bacterial genomes, and are conserved in around 700 gene promoters of human, mouse and rat genomes. This year, in a *Cell Reports* paper, Chowdhury's research group cracked the mechanism of how the G4 region controlled the expression of telomerase, and hence held the key to some cancers.

An important player in this game is a protein called TRF2. Ananda Kishore Mukherjee, a PhD student in Chowdhury's laboratory, observed that TRF2 can bind to telomerase, the enzyme that is involved in protecting telomeres. Mukherjee had analysed that TRF2 binds at around 20,000 sites in the human genome and regulates activity of many gene promoters that harboured G4 sequences. This suggested that TRF2 is not only confined to telomeres but can park itself in many G4-rich sequences, some of which can regulate telomerase expression in the cell.

So, Chowdhury's group showed that TRF2 binding to the G4 shut down the expression of telomerase in adult cells. Some mutations inhibit the ability of the G4 to fold into stacked sheets, and therefore disrupt its structure. The disrupted structure does not let TRF2 to bind, which means that the expression of telomerase is not shut down. With the telomerase

being produced constantly, the cell does not die, but it continues to divide. The actual mechanism would be much more nuanced, but the main culprits seem to have been caught.

Chowdhury's PhD student Shalu Sharma confirmed through experiments that TRF2 binds to the telomerase promoter – the genetic switch of telomerase synthesis – and shuts down telomerase expression. "Studies by Sharma in the Chowdhury lab provide evidence that TRF2 may have functions in addition to binding to telomeric DNA," says Jerry Shay, telomere biologist and Distinguished Professor of Cell Biology at the University of Texas Southwestern Medical Center, in an email communication. "Importantly, this study provides novel insights into potential therapeutic opportunities to target cancer," adds Shay.

Logic suggests that one way to treat such cancers is by shutting down telomerase activity and thereby letting the telomeres shorten in length once again. Shutting telomerase activity requires the restoration of the G4 sheet structure lost due to mutations. The genetic mutations in the DNA cannot be reversed, but scientists hoped to discover small molecules that could restore the original structure of the G4.

The importance of G4 in gene regulation suggests their significance as drug targets in a wide variety of diseases, especially cancers and infections. They offer an advantage as drug targets over their protein counterparts. Most anti-cancer drugs work by jamming the function of proteins that are overexpressed in cancer cells, but all proteins may not bind all drugs owing to constraints posed by either their size or their structure. There is a specific fit for the protein-drug duo. Certain cancer cells can become resistant to drugs used in clinical practice, and thus pose requirements for novel molecules.

Binding molecules circumvent this problem as they target the G4 DNA structure to shut the synthesis of wrong proteins. Quarfloxin was the first G4 targeting anticancer molecule and it has progressed to phase II clinical trials against several types of cancers, and other approved drugs are under study for G4 binding properties.

Shalu Sharma, whose studies in Chowdhury's lab provided evidence that TRF2 may have functions in addition to binding to telomeric DNA.

PHOTO: BY SPECIAL ARRANGEMENT

PHOTO: BY SPECIAL ARRANGEMENT

Jyotirmayee Dash (*second right*) and her students synthesised a novel molecule that can bind to G4 in a cancer gene promoter and suppress its expression in blood cancer cells.

The G4 can turn out to be important for solving three big healthcare problems: cancer, viral infections and bacterial infections.

Jyotirmayee Dash, chemical biologist and professor at the Indian Association for the Cultivation of Science (IACS) in Kolkata, designs molecules that can bind to G4. Unlike Chowdhury, who studies G4 in live cells, Dash looks at how small molecules can interact with G4 in a solution. She had earlier worked with Shankar Balasubramanian, a Cambridge professor who had proved the existence of G4 in human cells. Not all G-rich sequences would form a quadruplex structure inside the cell, and such studies are important to figure out how a specific sequence can fold into an actual quadruplex structure. In a recent piece of research published in *Chemistry Europe* journal, Dash and her students synthesised a novel molecule that can specifically bind to G4 in a cancer gene promoter and suppress its expression in blood cancer cells.

G4 has been shown to exist in a wide variety of organisms, including bacteria and viruses. Vivekanandan Perumal at the Indian Institute of Technology Delhi studies G4 in viruses, as a prelude to investigating ways of developing treatments against viral infections. Perumal got interested in the topic after listening to a talk by Chowdhury. "While listening to Shantanu, I thought that G4 secondary structures must be present in viral genomes," says Perumal. The area has not been studied well, and Perumal aims to explore G4 in viruses.

Perumal investigated the hepatitis B virus, which has ten subtypes that differ in the way they cause infection. Can these differences be explained by G4-based mechanisms? Perumal worked on a virus with a small genome, and found that it had only one G4 sequence not seen anywhere else in the genome. He showed that a disruption of a single G4 sequence affected every step of viral replication. He also found that the genome of herpes virus has dense G4 sequences.

In both herpes and hepatitis B viruses, G4 sequences were in regions responsible for viral infection. G4 evolution shows interesting patterns in viruses and their hosts. G4 are abundant in vertebrate viruses and very scarce in invertebrate viruses. "If you look at genomes of viruses that infect humans, they are rich in G4 such as herpesviruses," says Perumal. "On the contrary, if you analyse G4 in an invertebrate genome such as a mosquito, it has little G4. Likewise, viruses that infect mosquitoes lack G4 sequences." It is also a suggestion that G4 are good targets for antiviral drugs.

Meanwhile, Dash is investigating G4 sequences as targets for anti-bacterials. So, the G4 can turn out to be important for solving three big healthcare problems: cancer, viral infections and bacterial infections. •

A prescription change

Immunologist **Satyajit Rath** on why he changed career course, and whether we would have been safer in the wild.

SATYAJIT RATH is a doctor who became fascinated by the field of immunology and switched fields. After seven years' post-doctoral research in India and abroad, Rath joined the National Institute of Immunology in 1991 and stayed there till he retired in 2017. Now a visiting professor at the Indian Institute of Science Education and Research (IISER) in Pune, Rath spoke to **Hari Pulakkat** on the immune system and how his field of immunology has been changing of late. Excerpts:

It is unusual for a medical doctor to trace the career path you took. What attracted you to immunology?

It is unusual in India certainly, but not so in the global North. In the U.S., the so-called MD-PhD. researchers are common in life science research. As for what attracted me to immunology, there are a couple of answers. It is a field that deals with how individual organisms deal with the pressures and stresses of the external world. The immune system has to respond extraordinarily rapidly, and over evolutionary time it will face a variety of pressures from infecting microbes. As a result, the mechanisms involved in it have to be both very robust and yet in time must constantly change to adapt to local incidental circumstances. Immune systems, like all systems in the body, function on the basis of genes and molecules. But it deals with stresses created by a whole ecosystem. In the COVID-19 pandemic, whatever comes from bats and pangolins and whatever we are suddenly faced with, integrated with social inequity and global travel... that's what the system is faced with. So, there is a broad-spectrum perspective when one is studying the immune system. That makes it very attractive to somebody who has worked as a dilettante researcher with broad interests.

From an immune system point of view, do we face greater threats in modern life than in the wild?

Not really. Let me qualify that. I think we face different kinds of stresses in traditional life – as opposed to hunter-gatherer life. In each of these circumstances, the stresses are different. We know that because the COVID-19 virus spreads from breath to breath. Clearly, in small, crowded communities, in urban working-class hutment colonies in India, it will spread very rapidly. But in hunter-gatherer communities, which are small groups of people isolated from each other, it would not have spread so rapidly. On the other hand, urban hyper-crowded societies have far less unreliable access to clean water and adequate and reliable food than a hunter-gatherer society did. So there is a different set of potential infections that a hunter-gatherer society will face. I don't think they are more or less.

Would people develop a more robust immune system if they lived in the wild like the hunter-gatherer societies?

This is why I was stressing that the infection stresses are simply different in hunter-gatherer societies. So would you expect the immune system to look different? Yes. But would you expect it to be stronger or weaker? No. Simply different.

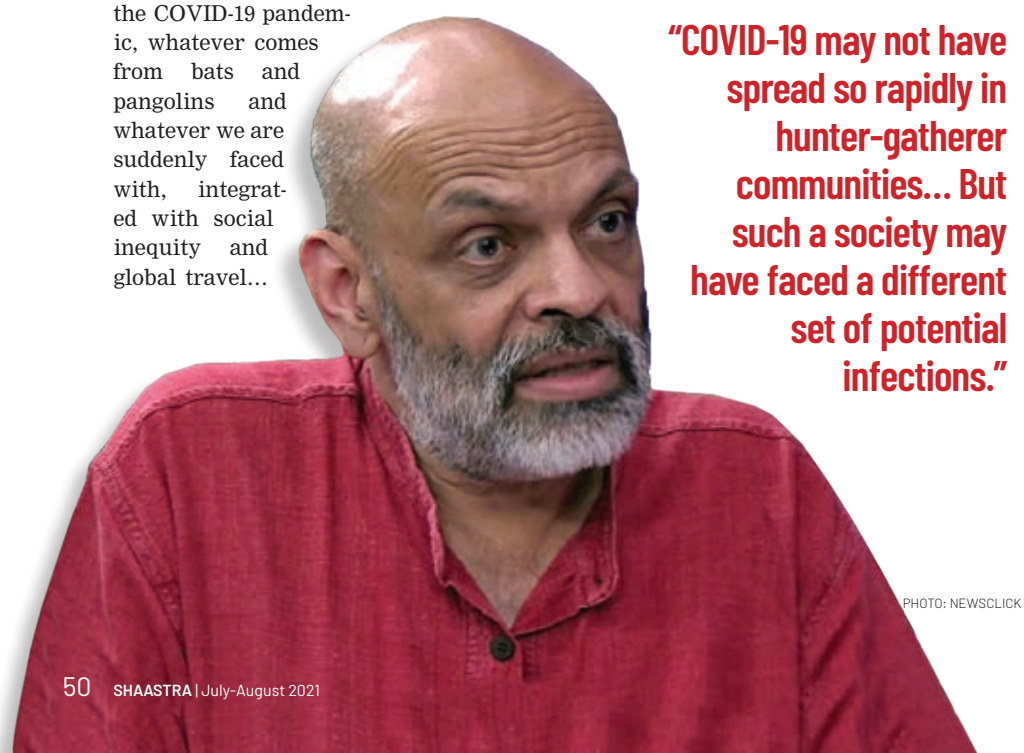
We've been hearing that early exposure to germs is essential for the development of the immune system. In affluent cultures, babies are not as exposed to germs. What are the consequences?

I think this is a mistaken approximation – or at least an oversimplification. When we talk about germs, we talk about microbes that cause disease. In reality, we live surrounded by microbes that don't necessarily cause disease. In the wealthiest communities of the world, everybody's bodies have flourishing communities of microbes. So the baby encounters, in the moments of its birth, microbes. And it begins to acquire them from the mother's skin as the baby begins to drink milk. So microbes are an ever-present reality for us. Microbes being important is not the same thing as disease-causing microbes being important.

How has your field changed in the last decade? What have we learned about the immune system?

There is a technological way in which the field has changed enormously. Conceptually the field has changed only in incremental terms. The technological shift (that) immunology has undergone is seen in the ability to collect massive amounts of molecular, cellular and organismal level data. We can sequence individual cell DNA; we can sequence all the RNA the cell is making; we can characterise all the proteins that an individual cell is making... That kind of data-gathering ability has provided a more dramatic change for the discipline of immunology than for other disciplines – in part because the immune system consists of cells that are moving in the body all the time. Because we have no idea where the microbe will enter the body, we have a trafficking system. This means that the same cell is likely to be doing different things in different places in the body. To be able to track that at the level of the individual cell, at the molecular level, and to couple that with whole-body imaging methodology that has also developed, and to see the consequences of the diverse cellular behaviours, this is what has made a massive difference to the field. •

"COVID-19 may not have spread so rapidly in hunter-gatherer communities... But such a society may have faced a different set of potential infections."



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Creating Possible

What's cooking in the lab?

With cultivated meat, scientists give carnivores something to chew on while also preserving the environment.

Manupriya

In 2011, when Biman B. Mandal set up his lab at the Indian Institute of Technology Guwahati (IITG), his plan was to grow cells, tissues, and organs to help patients with organ damage due to disease or injury. As the lab gained expertise in growing cells of different kinds, Mandal became interested in another type of cell culture: growing edible cells in the lab. In other words, cultivating meat. "We were already growing muscle cells in the lab, and meat is also made up of mostly muscle cells. It seemed obvious to give it a go," said Mandal, Professor in the Department of Biosciences and Bioengineering, IITG.

After pondering for a while on the type of edible cells to grow, Mandal and his colleagues zeroed in on chicken cells, since chicken is widely eaten across India. They extracted muscle progenitor cells from chickens and placed them in a nutrient medium in which the progenitor cells were able to divide and grow into muscle cells.

As simple as it may sound, this process required several iterations. For starters, the nutrient medium – food for cells – needed to be just right for cells' growth and to be free of components that are unpalatable to humans. They also needed to create a scaffold, or a structural material, on which the cells could grow. Again, the scaffold had to be made of edible materials. As the cells grew, they had to be protected from infections without using antibiotics.

Soldiering on, the IITG team was able to tackle the challenges that came its way and was able to grow chicken cells in its lab by 2019.

That same year, almost 2,000 km west of Guwahati, two Jawaharlal Nehru University-based researchers, Siddharth Manvati and Pawan Dhar, started up ClearMeat in New Delhi. ClearMeat had developed its own technology to grow chicken cells in the lab. The product, comparable to chicken *keema* (mince), also requires the right nutrient medium, a scaffold, and sterile conditions to grow, but it was developed independently. The underlying technologies are their trade secrets; for instance, Manvati and Mandal don't know what the other team's nutrient medium is composed of.

PHOTO: MOSA MEAT

COST CONSIDERATIONS

However, what's common to the two teams is that they have both worked hard to develop a nutrient medium or cell-growth medium that is free of animal products like serum – and which is not expensive. The cost consideration is critical. In the long run, the cost of the growth medium will be a major determinant of the cost of meat cultivated in labs, which in turn will decide its commercial success on the supermarket shelves.

Cell culture – the science of growing cells in a lab – is a fairly old technique, and scientists use it routinely. It is, however, highly dependent on the use of foetal bovine serum (FBS) as a growth medium. Not only is FBS very expensive, it is not suited for growing chicken cells, for the reason that consumers may balk at eating chicken cells grown in calf serum. Which is why the researchers felt the need to grow their cultivated meat in newer types of growth medium.

"Even the most inexpensive serum-based growth medium in the market costs ₹1,500 for 500 ml," says Mandal. Against that, "our in-house growth medium costs only ₹50 for 500 ml, and is composed solely of cereals and edible products," he added.

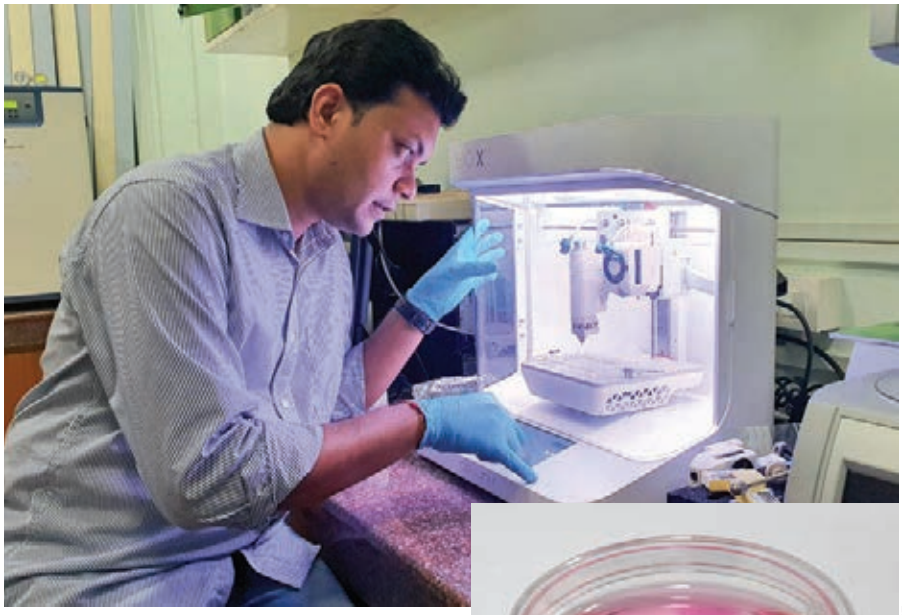
The IITG team has patented its formulation and hopes to sell it to anyone interested in trying out a new growth medium for routine cell culture experiments. However, it may be a while before the formulation becomes available since the processes are still being worked out. Similarly, ClearMeat also has plans to take its growth medium, branded ClearX9™, to the market.

As for the cultivated meat itself, the price will be an important factor that will determine its commercial success based on consumer acceptance. Manvati says ClearMeat's chicken mince will be available at about ₹850-900 a kilogram, which he notes, is "comparable" to the price of processed chicken meat in the market, but will come down further with scale of production.

However, for cultivated meat to achieve price parity with regular chicken meat, which retails at about ₹200 per kg, will take at least 10 years, says Varun Deshpande, Managing Director of Good Food Institute India (GFI-India). GFI-India is a not-for-profit working to enable the smart protein industry in India, which includes cultivated meats, plant-based proteins, and fermented proteins.

THE 'TASTE TEST'

However, even more than the price, lab-cultivated meat will face another stern test of consumer acceptance: its taste and texture, and how close they are to natural meat. It is the proportion of muscle and fat in the meat that often determines the taste and texture. Researchers say they can modulate the amount of fat and muscle to suit consumers' requirements.



Prof Biman B. Mandal in IIT Guwahati, where his team cultivated chicken cells in the laboratory. (Inset) The cultivated meat.

PHOTOS: BY SPECIAL ARRANGEMENT

Siddharth Manvati, co-founder of ClearMeat, a New Delhi start-up that harnesses cell culture technology to cultivate meat.

The more closely cultivated meat recreates the experience of eating regular meat, the more likely that consumers will place repeat orders for it.

In 2020, ClearMeat wanted to conduct a public tasting event for its chicken mince equivalent product but couldn't do it because of the COVID-19 pandemic. The company did, however, conduct a small private tasting event, where Manvati and some of his colleagues tasted the ClearMeat product. They cooked it at home with regular Indian spices and rice. "You could call the dish chicken *keema* rice," says Manvati. The taste, however, was not very close to that of regular meat – perhaps owing to the "lack of fat cells" in ClearMeat's chicken mince, he reckons. This experience led the team to make changes in its product to improve the taste and texture and get them closer to regular meat.

Even as researchers alter and improve their products to match the real thing, they wonder how well they will be accepted by the consumers.

Some studies have tried to assess this. For example, a 2019 survey of 1,024 urban Indian consumers by GFI-India found that:

- 56.3% of the participants were very or extremely likely to buy cultivated meat;
- 32.9% were somewhat or moderately likely to buy it; and
- 10.7% were not at all likely to buy it.

Additionally, increased familiarity with these foods tends to drive up the acceptance rate, so India is expected to have a big market for cultivated meat over time, says Deshpande.

CULTIVATED vs REGULAR MEAT

Many studies have made the case that cultivated meat and other forms of smart proteins are more environment-friendly and sustainable sources of protein than regular meat. Production of regular meat emits more greenhouse gases, requires more land and more water in comparison to cultivated meat.

A recent industry-based life cycle assessment (LCA) and techno-economic assessment (TEA) by GFI claimed that cultivated meat reduces the carbon footprint of beef, pork, and chicken by 92%, 52%, and 17%, respectively, when production facilities where cultivated meat is grown are powered by renewable energy. Cultivated meat also reduces land use up to 95% compared to beef, 72% compared to pork, and 63% compared to chicken, it claimed.

Another critical consideration is that the regular meat industry relies heavily on antibiotics to keep animals disease-free. This eventually contributes to antibiotic resistance. Cultivated meat, on the other hand, is grown in sterile conditions, so antibiotics are not required to keep infections away. Because of the sterile growth environment, chances of contamination are "very low" for cultivated meat, says Rama Tentu, research fellow at GFI-India. Additionally, the less-than-hygienic conditions in slaughter-houses and animal farms mean that "cultivated meat will always have a lesser microbial load than regular meat," she notes.

NEW PROTEIN SOURCES

As the global population increases, the demand for proteins is expected to rise. The 2012 edition of *World Agriculture Towards 2030/2050*, a report published by the Food and Agricultural Organization projected that global production and use of meat would rise from 258 million tonnes in 2005/2007 to 455 million tonnes in 2050. The global population is expected to rise to 9-11 billion people by 2050, which will lead to a commensurate rise in the demand for agricultural products.

A 2021 study in the *Annual Review of Food Science and Technology* journal points out that "a leap in traditional agricultural productivity is necessary to meet the rising demand" and that technologies like cultivated meat offer a "potential solution".

India, where a large share of this growing population will reside, will require adequate proteins to nourish the large populace. Indian diets are typically deficient in proteins and the country is home to a huge number of malnourished children. Smart proteins like plant-based meats and cultivated meats will perhaps be able to compensate for this deficiency in the great Indian *thali*.

FROM LAB TO MARKET

The first ever cultivated meat burger was tasted at a public event in London in 2013. The meat for the burger was cultivated at Maastricht University, the Netherlands, by Mark Post (*see box*), a tissue engineering scientist. He has since launched Mosa Meat, a cultivated meat company.

PHOTO: BY SPECIAL ARRANGEMENT

Varun Deshpande of Good Food Institute-India, which is working to enable the 'smart protein' industry in India.

The more closely cultivated meat recreates the experience of eating regular meat, the more likely that consumers will take to it.

From then onwards, the cultivated meat industry has expanded dramatically. Several companies across the globe are working on producing a variety of cultivated meats. For example, U.S.-based UPSIDE Foods is working on producing cultivated chicken, beef, and duck. U.S.-based BlueNalu and Singapore-based Shiok Meats are working on cultivated seafood. Dutch start-up Meatable is working on pork.

For some companies, the transition from lab to market has already begun. In December 2020, Singapore became the first country to allow the sale of cultivated meat. The Singapore Food Agency granted safety approval for "chicken bites" produced by Eat Just, a U.S.-based cultivated meat company.

SuperMeat, an Israel-based food tech company, is conducting public tasting events for its cultivated chicken.

THE INDIAN REALITY

In India, however, the cultivated meat industry is still at a nascent stage. Its success depends not only on how much funding the early movers in the industry are able to attract but also on the emergence of an ecosystem that helps this industry thrive. There is a felt need for a focus on training and on nurturing talent in this industry – and for support to be made available to start-ups making products or platforms that make it possible to grow cultivated meat at scale. One example of such a start-up in India is the IIT Bombay-based Myoworks, which makes scaffolds on which cultivated meat can be grown in labs.

Industry players feel the need for sustained government support in the form of grants and also clearly laid-out regulatory guidelines. As the industry is still developing, it is perhaps only to be expected that the regulatory guidelines will evolve with time, but the authorities shaping these regulatory frameworks should ensure that cultivated meat "is subjected to the same checks and tests for safety as the regular meat," says Deshpande. Also, "safety testing methods should be developed using the latest scientific knowhow," he adds.

Strikingly, the COVID-19 pandemic has forced many meat-eaters to re-evaluate their food choices and opt for animal-free food products. The regular meat industry is going through a churn and is additionally battered by diseases like avian flu and swine flu. Not enough is as yet known about how all this will affect consumer behaviour in the long run, but cultivated meat industry players clearly see it as an opportunity for them to step up with an alternative.

"The long-term prognosis for the smart protein sector remains hugely positive," says Deshpande. "It offers a means of resilience even to legacy animal meat producers who may want to future-proof their business." Now that's a meaty proposition that producers will find hard to pass up on. •

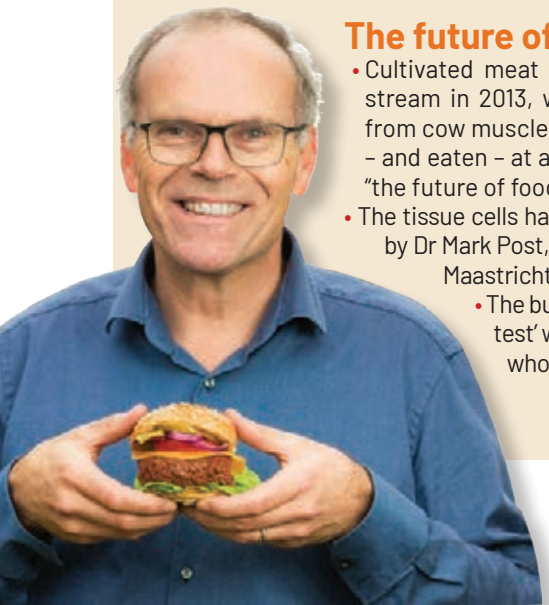


PHOTO: MOSA MEAT

Dr Mark Post with the $325,000 burger, made with cultivated meat in 2013.

The future of meat

- Cultivated meat made it to the culinary mainstream in 2013, when a 'beef' hamburger made from cow muscle grown in a laboratory was fried – and eaten – at an event in London to showcase "the future of food".
- The tissue cells had been cultivated in a laboratory by Dr Mark Post, a tissue engineering scientist at Maastricht University.
- The burger didn't exactly pass the 'taste test' with flying colours: a few of those who sampled it said it was a little pale, and lacked in juiciness and seasoning.
- Others, however, gave it full marks for "mouth feel".
- The project cost – an estimated $325,000, which made it the world's priciest burger! – was bankrolled by Google co-founder Sergey Brin.
- Brin was evidently motivated to back the project owing to concerns about the sustainability of meat production and animal welfare.
- Funding for start-ups in the cultivated meat space has increased substantially since 2013. According to a 2020 report published in the *Trends in Biotechnology* journal, from 2015 until early 2020, the amount of publicly disclosed capital invested in cultivated meat companies touched about $320 million.

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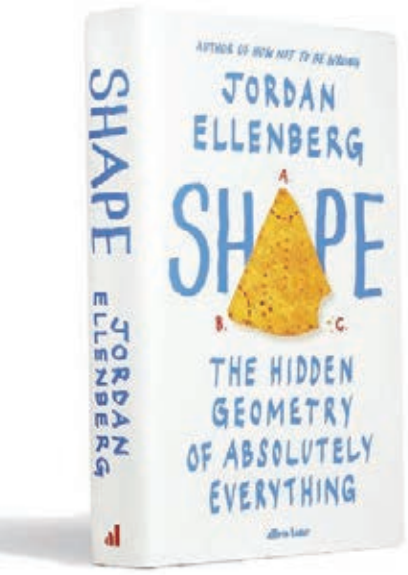
Why geometry is gorgeous

Jordan Ellenberg opens our eyes to the joyous geometry of everyday things, and offers us new ways of looking at the world.

PHOTO: MATT RUDELS

In his riveting book, Jordan Ellenberg gives geometry new shape and dimension altogether.



Shape: The Hidden Geometry of Absolutely Everything

By **Jordan Ellenberg**

Published by Allen Lane

480 pages; £20

You'll find geometry in the unlikeliest topics: Cicadas and primes, how sets in tennis are won and lost, and the efforts to redraw political constituencies.

Dilip D'Souza

My late mother-in-law was a gorgeous woman. She was also a professor of psychology, a well-known writer in Marathi and the spirit behind a group of women who sang and told stories about Sant Dnyaneshwar. She rounded out her interests and personality with a love for geometry. Every now and then, I'd offer her some intriguing puzzle that had foxed me. Her eyes would light up, she'd settle into a chair and plug away, invariably beating *me* – the guy with engineering and CS degrees – to the solution.

There's something of that polymath spirit in this book, which is why, as I read it, memories of her cropped up every now and then. I think she would have delighted in greedy algorithms, or prime numbers and cicadas, or the "geometry of our way of speaking"; delighted, in other words, at how Jordan Ellenberg shows us geometry everywhere, how he gives geometry new shape and dimension altogether.

The challenge writers face – "how can I give my reader something to think about?" – is in some ways the mirror image of the anticipation their readers bring along: "what am I going to get out of this book?" On nearly every page in *Shape*, you can sense Ellenberg tussling with and relishing that challenge. He seeks above all to take an ancient discipline – his book starts with the great Euclid's *Elements* – and offer you new ways of looking at it. Those then offer you new ways of looking at our world.

You might say: "But this is geometry he's talking about! What new ways?"

Well, this is no longer about congruent triangles and the sums of angles and proving some possibly obscure little truth from "first principles", satisfying though that may be. Ellenberg goes beyond that to all manner of subjects he sees geometry in, so much so that after a point he stops mentioning the subject. For by then he's writing about geometry almost as a way of thinking, of reasoning about the world. In fact, as early as on page 2, he drops a broad hint that this is where he's headed: "Geometry is still there when the rest of our reasoning mind is stripped away."

One way I could give you a sense of what Ellenberg means is the sheer range of the subjects he explores. Here's a sample: Cicadas and primes, how sets in tennis are won and lost, the "purely abstract space of the English language", the new Pepsi logo, and nefarious efforts to define electoral constituencies. There's geometrical thinking in all of that, and Ellenberg delights in opening doors, and minds, to this smorgasbord.

The Random Walk Theory

For example, early on, Ellenberg tells us of a 1904 lecture that he calls "the first glimmer of a new geometric theory that was about to explode into physics, finance, and even the study of poetic style: the theory of the random walk." Yet, the speaker wasn't a mathematician. It was the Almora-born doctor, Ronald Ross, who won the Nobel Prize in Medicine in 1902 for his research into how malaria is transmitted. His lecture was titled "The Logical Basis of the Sanitary Policy of Mosquito Reduction".

In such a lecture, just what was geometric?

Ross was speaking of ways to eliminate mosquitoes. What if you marked out a circle and drained all the water bodies inside it? Mark a large-enough circle and you might just produce a mosquito-free, thus malaria-free, region. Ross wondered about a mosquito born outside this circle: "During its life it wanders about... After a time it will die. What are the probabilities that its dead body will be found at a given distance from its birthplace?"

Not that Ross was on hands and knees scouring his circle for dead mosquitoes. But he was asking a thoroughly mathematical, or geometric, question. Given a mosquito's unpredictable wanderings – an instance of what came to be called a random walk – what is the chance that it will turn up in the centre of our marked circle? Or put it like this: how large would the circle have to be for this probability to become negligible? Because that's how we'll know how efficient our efforts to free the region of malaria have been.

Think of mosquito flight lines and turn angles, and suddenly the insect's meandering is a geometric construct that we can analyse mathematically. Of a simulation of ten thousand mosquito flights he once followed, Ellenberg writes: "Sometimes the mosquito sticks around one area for a while... sometimes (it) appears to acquire a brief sense of purpose and manages to cover some distance. Watching animation of this process, I have to tell you, is unreasonably captivating."

Sure, you say, he's a mathematician! Of course he finds this stuff "unreasonably captivating"! And yet the power and charm of this book is that

Ellenberg manages to captivate his reader as well, and I think that's because of the smorgasbord he offers us. In particular here, he's right about random walks: the idea – the mental image, really – turned out to be an enormously useful tool in all kinds of fields, some of which you wouldn't even think of as mathematical.

What's also refreshing about the book is that Ellenberg pulls no punches, names names. Like Republican politicians intent on redrawing political constituencies to ensure their electoral dominance. Like a certain "US Government official" named Trump.

The 'Pepsi ratio'

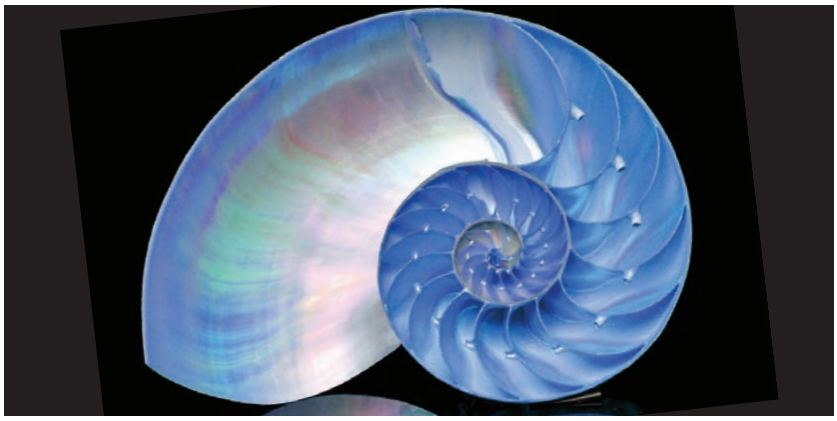
Like Pepsi. Towards the end of an examination of the number φ (*phi*, pronounced 'fee'), often referred to as the "golden ratio", he tells us how "put a φ on it" became a mantra for lazy marketing. "You could buy jeans whose golden proportions were flattering to your rear", for example, or lose weight by "eating proteins and carbs in golden-ratio proportions." Yet this empty-headedness pales in the face of "the greatest work of mystical geometric hoo-hah ever produced": Pepsi's "globe" logo, launched in 2008.

To Ellenberg, a 27-page booklet from the marketing firm, the Arnell Group, managed to suggest that Pepsi and the golden ratio are natural partners (!) because "the vocabulary of truth and simplicity is a reocurring phenomena (sic) in the brand's history." If that frantic hyperbole isn't enough to make you gag, the Arnell rag placed the logo at the triumphant climax of "five thousand years of science and design including Pythagoras, Euclid, da Vinci, and somehow the Möbius strip." And, of course, it also tried, not very subtly, to offer a new name for the golden ratio: 'The Pepsi Ratio'.

Somehow the name hasn't caught on. More seriously, in this passage, Ellenberg delves into what we mean when we call numbers like φ and π "irrational". That's a fundamental notion in number theory, the irrational number. But he uses a geometric view of numbers to explain the notion, and in a way that even a schoolkid familiar with fractions will understand. Along the way, we learn that there are fractions that are relatively good approximations for π – 22/7, or 355/113 – and other irrational numbers.

There's a purpose to this analysis. Ellenberg is leading up to something that, to me, is the beating heart of this book, but just a glimpse of the spirit that animates the mathematician in love with his craft. "Here's a beautiful fact," he writes, and note what he calls "beautiful": "in a way that can be made quite precise, φ, out of all real numbers, is the one that's least well approximated by fractions." In fact, φ is "the *most irrational* irrational number. That, to me, is a jewel."

Truly, those lines stopped me in my tracks. Now it's no secret that mathematicians see elegance and beauty in places that would be a mystery to people from outside the field. But here Ellenberg leads us to the jewel and tells us just why he finds it beautiful. It speaks of the spirit that skeins through this book like the Milky Way on a starlit night. To me, it's almost, maybe even unreasonably, moving.



PHOTOS: SHUTTERSTOCK

There are also Ellenberg's experiments with a piece of software called Word2vec. Feed it a heap of text and it produces a thicket of connections between English words, established by how we use them in the language. Ellenberg calls this a "geometry of our way of speaking".

One of the lines in this geometry is a "feminization vector" that takes you from "he" to "she", from "King" to "Queen". Then you try it on "stunning", and it takes you to "gorgeous". He wonders as I wondered: does this mean "that in some mathematical and universal and utterly objective sense, gorgeousness is the feminine version of stunningness?"

Certainly not. Instead, what it suggests is something slightly different: that "when English speakers want to talk about stunningness and we're talking about a woman, we have a statistically detectable habit of saying 'gorgeous'."

The man is so right. When I think of so many beautiful women I've known, the word "gorgeous" springs to mind. Case in point: check the first sentence of this review.

She would have loved this book. •

The golden ratio appears in nature, such as in the nautilus shell. Given its aesthetic quality, designers and architects invoke it in everyday objects – but marketers hype it up, as Pepsi did with its 'globe' logo, launched in 2008.

Once a computer scientist, Dilip D'Souza now writes on mathematics – and other beautiful things.
@DeathEndsFun

The sound of bad judgments

Strategies to shut out 'noise', or unwanted variability in judgments, which imposes high economic and social costs.

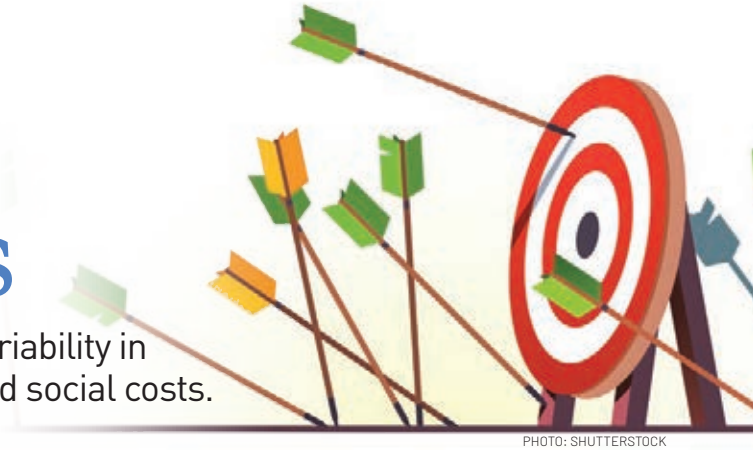


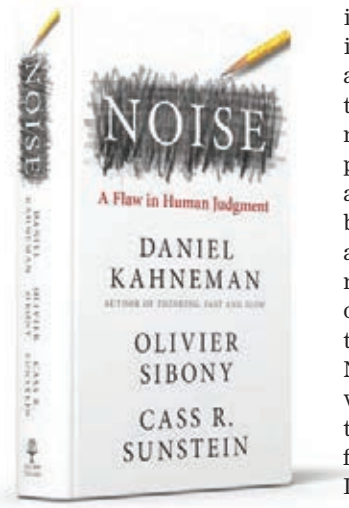
PHOTO: SHUTTERSTOCK

Venky Vembu

Two research papers published in a recent issue of *Surgery* journal starkly illustrate one of the more inexplicable idiosyncrasies of medical science: the contrasts in the judgments of two sets of professionals while looking at the same data. The professionals had been called upon to decide whether the use of a particular medical equipment during surgery to remove an inflamed appendix would increase or decrease the chance of an infection. They drew diametrically opposite conclusions even though their respective reasoning was rooted in the same data pool.

Diversity of opinions among medical professionals is, of course, highly consequential – since they deal with life-and-death matters. But such divergence is common enough in other fields as well. In the insurance industry, for instance, underwriters quote premiums for risks, and claims adjusters assess the value of future claims. While they may rely on actuarial science models, in the real world, their judgment calls, which hold enormous financial consequences for the insurance firm, have been known to vary in a wide range. And in the realm of criminal sentencing, there are countless instances of two people, convicted of the same crime, receiving vastly different penalties. On occasion, judicial outcomes hinge on frivolous considerations: whether it is a hot day, how the local football team fared the previous day, or even whether the hearing was held after a meal break!

In some life situations, of course, variability in professional judgments is not unwelcome – and may even be desirable. When multiple teams of researchers are working to develop a COVID-19 vaccine, say, we would want them to approach the problem from different angles. We also expect diversity of opinions from film critics or from wine-tasters, even when they've sampled the same produce. But the problem arises with *unwanted* variability in professional judgments, particularly among people who are expected to agree. Psychologist Daniel Kahneman, business strategist Olivier Sibony and legal scholar Cass R. Sunstein call this *noise*.



Noise: A Flaw in Human Judgment

By **Daniel Kahneman**, **Olivier Sibony** and **Cass R. Sunstein**

Published by Hachette Book Group

375 pages; £25

Bias vs noise

As the authors frame it, *noise* is different from *bias*, even though both are different components of error. Bias is a systematic deviation; if the errors in judgements all follow in the same direction – for instance, if ethnic minorities are routinely penalised in disproportionate numbers – that reflects bias: it manifests itself in an archer who consistently misses the bull's-eye, but all of whose arrows are clustered in one off-centre area. Noise, on the other hand, is variability of error, where the errors in judgements follow in many directions. It is random scatter, as happens with a loose cannon: in the pictorial illustration above, it's when an archer peppers the target without a pattern, to the point where it's impossible to say where the next arrow might land.

Organisations and professional groups may be afflicted by both bias and noise, but whereas they may even be aware of their inherent bias, they don't really know the extent to which they are susceptible to noise.

Showcasing many real-world examples of noise and its effect at work and in broader society, Kahneman, Sibony and Sunstein detail many tools to cancel it out, improve judgements and prevent error by employing so-called *decision hygiene* techniques. Two of these noise-reduction strategies merit particular attention, given that the authors place enormous faith in them. The first is by *aggregating multiple independent judgments*. That is, by drawing on the "wisdom of crowds" – or crowdsourcing opinions and then averaging out different judgments. But that can work only if the crowd constituents are immune to 'groupthink' pressure, which is a challenge as exemplified by conformity experiments.

The other strategy – of harnessing rules, formulas and algorithms over humans while making predictions – is a recurring theme for the authors, although they fleetingly acknowledge the malefic effect of "algorithm bias". To give them their due, the formula-based noise-cancellation strategy did demonstrably work for a while, in specific domains. For instance, one of the broadest sets of prison sentencing reforms in the U.S., propelled in the 1970s by judge Marvin Frankel, saw the dilution of much of the "unfettered discretion" that judges and parole authorities enjoyed while imposing and implementing sentences. In its place, the reforms introduced mandatory "sentencing guidelines" – a check-list of sorts – that established a restricted range for criminal sentences.

But the seeds of failure were embedded in those very provisions. Judges bristled at the dilution of their discretionary powers, and pushed back against their implementation. Over time, the guidelines were made 'advisory', which effectively rendered them toothless.

Silence is impractical

In other words, as Kahneman, Sibony and Sunstein point out, the right level of noise in an organisation or society may not be zero. In some realms, it is infeasible – or too expensive – to eliminate noise. Or, as the experience of shackling judges' discretionary powers established, efforts to eliminate noise may create the perception that humans were being reduced to automatons, and dampen morale among critical stakeholders.

Even so, the authors make a persuasive case for organisations, and the pillars of civil society, to embrace these noise-reduction strategies – in the interest of fairness and efficiency. Their prose may occasionally border on the dense, but in training their collective attention on a little-researched aspect of flawed decision-making, they light up the path away from the shadows of the mind where cognitive biases – and noise – play tricks. •

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6kW PMS motor
26 Nm instant torque
Top speed 80kmph

Intelligent.

Onboard navigation with 4G LTE
Reverse assist
Bluetooth control
Over-the-air updates

Powerful.

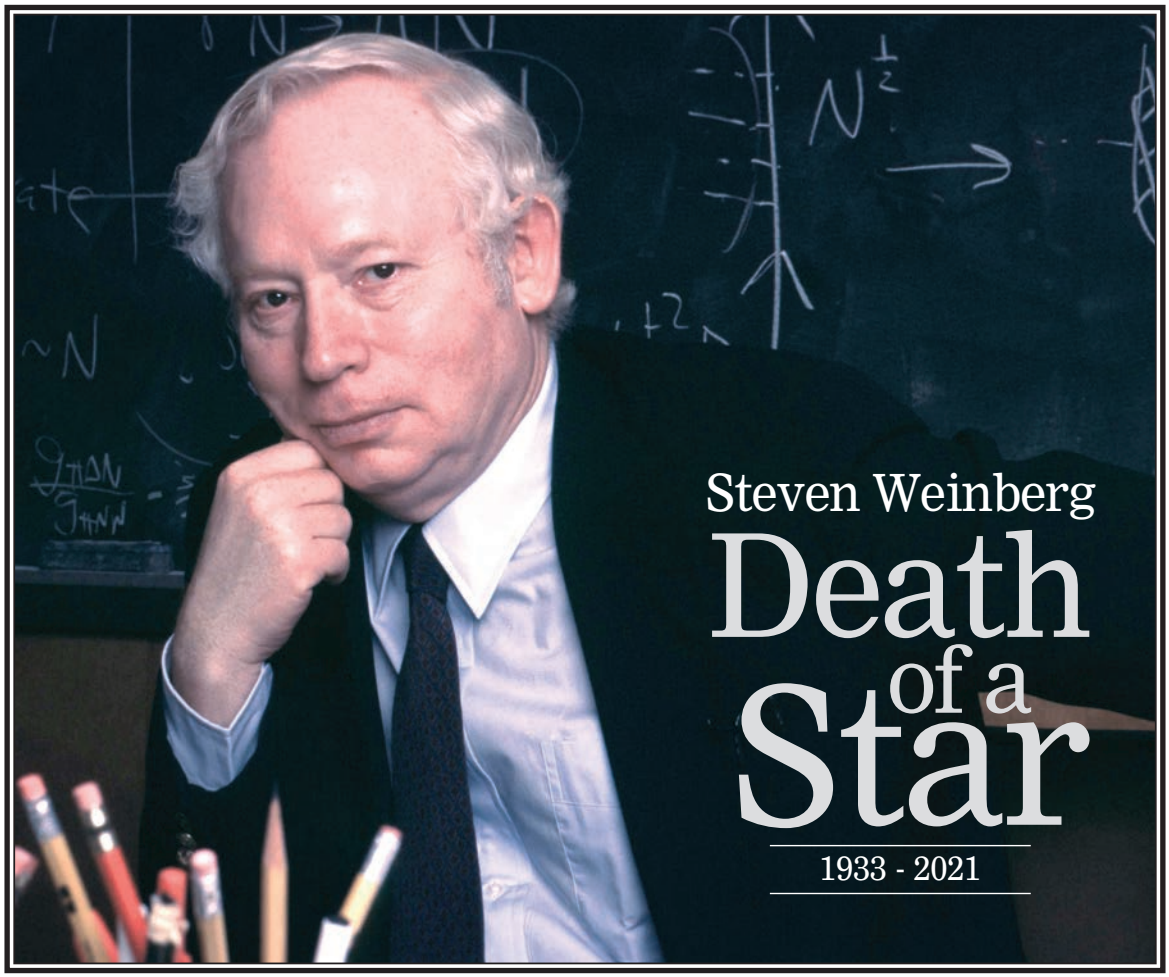
2.9 kWh battery pack with
new 21700 lithium-ion cells
Millions of kms of ride statistics

Expanding Network.

18 cities and counting

Born in IIT Madras. Growing at Warp Speed.

ATHER



Steven Weinberg
Death of a Star

1933 - 2021

PHOTO: LARRY MURPHY/THE UNIVERSITY OF TEXAS AT AUSTIN

The theoretical physicist and astronomer brought a simplicity to our understanding of the universe – and communicated a joy in the beauty of science.

Dilip D'Souza

Possibly Steven Weinberg's most famous scientific paper was published in 1967. Even today, 'A Model of Leptons' is regularly described as "seminal" and "iconic", the theory it lays out "simply written" and "neatly constructed" and "elegant".

Yet 'A Model of Leptons' is just three pages long.

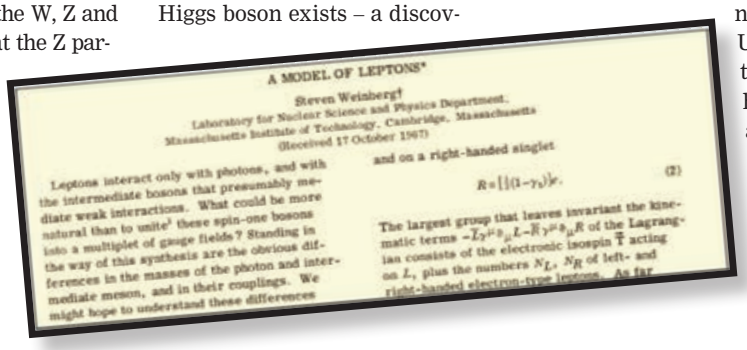
That startling fact might just be a measure of this theoretical physicist and astronomer who died on July 23. The paper offered a theory that explained interactions between fundamental particles of physics, and suggested that it would be useful to search for three specific ones (later to be called the W, Z and Higgs particles). It predicted that the Z particle, in particular, would generate "weak neutral currents".

You don't need to know what all these terms mean to understand the impact they had on the conduct of science in the years since, though it took a few years for physicists to fully grasp the implications of the paper. Once that happened, by 1976, it had become the most-cited research paper in high energy physics, and it stayed atop that list for an astonishing 30 years. Over a half-century later, it remains relevant and important: one estimate is that today, it is cited by other scientists three times a week.

Truly, some of the most ambitious efforts in experimental physics were inspired by Weinberg's succinct three pages. At CERN, the European Organization for Nuclear Research, in Switzerland, for example, scientists first found evidence of those "weak neutral currents", found evidence of the W boson, and in 2012, used the Large Hadron Collider to show that the Higgs boson exists – a discovery that made headlines even in non-academic papers.

"It's what keeps you going as a theoretical physicist," Weinberg once said about that experimental confirmation of his theories at CERN, "…to hope that one of your squiggles will turn out to describe reality."

Steven Weinberg was born in New York in 1933. Science was an early passion, which is why, as a teenager, he studied at the well-known Bronx High School of Science. He graduated at 17 and went from there to Cornell University to earn an undergraduate degree in 1954. Three years later, he completed a PhD at Princeton University. In the years after that, he was on the faculty at the University of California, Berkeley, then at Harvard University from 1966, winning the Nobel Prize in 1979. In 1982, he moved to Austin and set up a theoretical physics group at the University of Texas, staying there for the rest of his life. Besides the Nobel, he



A MODEL OF LEPTONS*

Steven Weinberg†

Laboratory for Nuclear Science and Physics Department,
Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received 17 October 1967)

Leptons interact only with photons, and with the intermediate bosons that presumably mediate weak interactions. What could be more natural than to unite[3] these spin-one bosons into a multiplet of gauge fields? Standing in the way of this synthesis are the obvious differences in the masses of the photon and intermediate meson, and in their couplings. We might hope to understand these differences

and on a right-handed singlet

$$R=\tfrac{1}{2}(1-\gamma_5)e. \qquad (2)$$

The largest group that leaves invariant the kinematic terms $-\bar{L}\gamma^\mu\partial_\mu L-\bar{R}\gamma^\mu\partial_\mu R$ of the Lagrangian consists of the electronic isospin $\frac{1}{2}$ acting on L, plus the numbers N_L, N_R of left- and right-handed electron-type leptons. As far

His most famous scientific paper, published in 1967

collected a slew of other scientific awards. Last year, he won the $3-million Breakthrough Prize in Fundamental Physics, sometimes called the 21st Century Nobel. It recognised his "continuous leadership in fundamental physics, with broad impact across particle physics, gravity and cosmology, and for communicating science to a wider audience."

Those lines capture some of the essence of the man. While that 1967 paper was ground-breaking and eventually led to the Nobel, he remained an accomplished, influential physicist throughout his career. What's now considered the Standard Model of particle physics helps us understand how matter and forces in our universe are linked to each other, and the model owes a lot to Weinberg's work. He showed that it was possible to combine electromagnetism with what's called the "weak interaction" between particles.

He always claimed that he didn't actually start work with a plan to unify these forces. But at the time, physics was in a state of some chaos and uncertainty – a strong force here, a weak one there, these particles over here, but how did they fit together? Viewed in a certain way, one of the particles would have to be very massive. But viewed another way, the theory needed the particle to lack mass altogether. What was the theoretical framework in which contradictions like this coexisted – if they were actually contradictions to begin with, if they were not actually resolved? What might help us find a degree of consistency in it all?

Weinberg's work sought to answer such questions. Yet, as vital as the Standard Model is to physicists' understanding of the universe, Weinberg believed – as other physicists do – that there is an overarching theory in physics that will explain so much that we still don't know about forces and particles. For example, at very high energies, there's evidence that what physicists know as the electromagnetic and weak forces combine into an "electroweak" force. Can we find a single force that embodies the merging of the weak, the electromagnetic and the strong forces? Where does gravity fit? What is the theory that accounts for these threads?

Of course, this Grand Unified Theory remains a dream, defying the efforts of Weinberg and plenty of other physicists as well. But he pursued these questions throughout his career.

He also grew ever more interested in astronomy. This began after the discovery of cosmic background radiation, the so-called "leftover" radiation from the Big Bang, in the 1960s. Weinberg's work led him to write the book *Gravitation and Cosmology* in 1972, still a respected text. Describing a course he taught in 2017 on astrophysics, he wrote: "The course will cover various topics in astrophysics such as stars, both single and binary, the interstellar medium, and galaxies. It will emphasize calculations that can be done elegantly and analytically, with a minimum of complication." Note the continuing emphasis on elegance and spareness. (As an aside: I took several astronomy courses at the University of Texas in the late 1980s. I still regret never getting to meet Weinberg.)

But Weinberg had interests outside academia too. One of his lifelong passions was nuclear disarmament. He was a consultant for a while with his country's Arms Control and Disarmament Agency (ACDA), whose mission was "formulating, advocating, negotiating, implementing and verifying effective arms control, nonproliferation, and disarmament policies, strategies, and agreements." (ACDA was absorbed into the U.S. State Department in 1999.) He was a staunch supporter of Israel, once remarking that boycotts of that country "indicated a moral blindness for which it is hard to find any explanation other than antisemitism."

PHOTO: MAXIMILIEN BRICE/CERN

On a July 2009 visit to CERN, Weinberg (*left*) with Dr Peter Jenni, the then spokesperson for the ATLAS experiment.

Weinberg believed that there is an overarching theory in physics that would explain so much that we still don't know about forces and particles.

He believed deeply in the need to talk about the worth and joy of science to the outside world. But for him, this went beyond just communications about his research. In 1984, he delivered the Albert Einstein Memorial Lecture at the Israel Academy of Sciences and Humanities. He could have easily spoken about gravitation and cosmology, or weak neutral currents, or any of a hundred different ideas he had spent years exploring. But no. Instead, he titled his lecture 'Beautiful Theories'.

Now, plenty of mathematicians and physicists have spoken about beauty in their disciplines – so much so that it's almost a cliché. But Weinberg told his audience that he didn't want to just "say more nice things about beauty." For him, describing a theory as beautiful was akin to "what a horse trainer means when he looks at a racehorse and says that it is a beautiful horse" – not really that the animal is especially handsome, but that "this is the kind of horse that wins races." Clearly, this is a utilitarian and tangible idea of beauty. Analogously, a physicist's idea of beauty "is supposed to help the physicist select ideas that will help us to explain nature."

In 1999, he spoke at a meeting of the American Association for the Advancement of Science about another subject close to his heart: debunking what he saw as anti- or pseudo-science. In this case, he attacked "intelligent design" – the notion that the universe has been designed by, well, a god. Weinberg was an atheist, and was regularly called upon to examine what that meant for his scientific work. In this lecture, he built his case by contrasting the ways science and religion look at the world. Religion tells us that we live according to the dictates of a particular god and not another, he said, and is even willing to offer evidence for this assertion. But religion "cannot explain why this should be so." In contrast, take the laws of nature. We live by them too, but while physicists can't explain why we have those laws and not totally different ones, they can "explain why they are not slightly different."

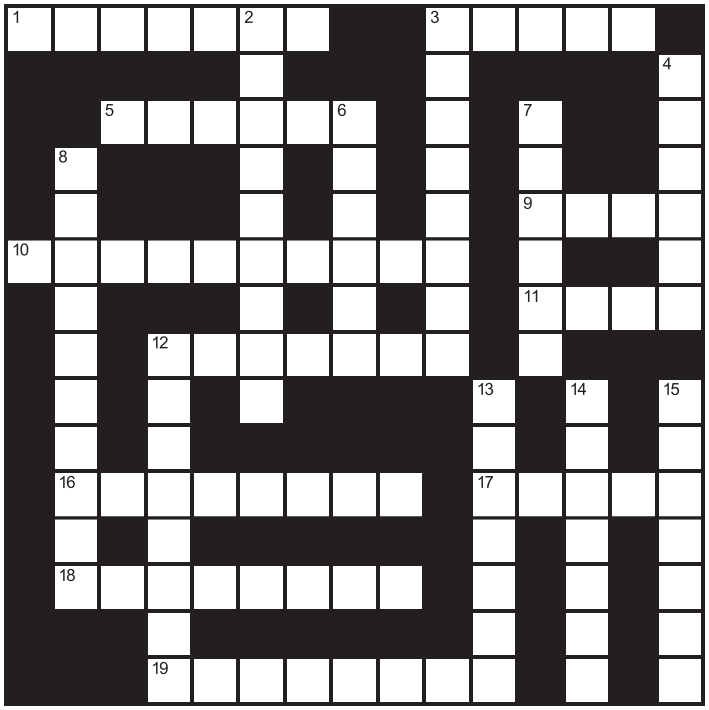
Science, he meant here, retains a certain humility about the universe, a keen sense of its inadequacies, that serves it well. Religion, on the other hand, is about assumed certainties, and Weinberg saw danger there.

And yet he was no vocal basher of religion or its practitioners.

In a 1998 interview with the PBS network, he said: "If there is no point in the universe that we discover by the methods of science, there is a point that we can give the universe by the way we live, by loving each other, by discovering things about nature, by creating works of art."

"Loving each other"? "Creating works of art"? An unusual point of view for a scientist, certainly. He so impressed his interviewer that day, Margaret Wertheim, that when he died, she tweeted: "Steven Weinberg has left this world. He was among the favourite interviews I've done with any physicist. Though we deeply disagreed about the value of religion in life, he was gentle, humble & truly interested in his fellow humans. A noble Nobel man." •

FunTech



COMPILER: KRISKROSS

ACROSS

1 It could be used to heat mug, bottles, pot (7)
3 Scientist in "Titanic" travelling west with boys on vacation (5)
5 Densely packed program — medicos gathered (6)
9 Mostly uncharged, outside nucleus... primarily a subatomic particle (4)
10 Roves around with king in mine, to get mineral — essentially, calcium titanate (10)
11 Some greet cheerily to make a deep impression (4)
12 Wear new guitar with iron coating? Not right (7)
16 Stone you and I will measure for hardness (8)
17 Friend wins nothing but bronze, say (5)
18 Container right inside cubicle at work (8)
19 Cut ice with hollow element possibly having lowest melting point (8)

DOWN

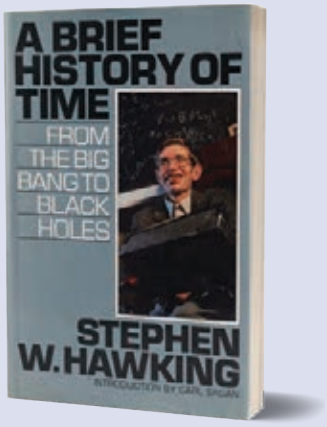
2 Arrive, carrying a proposal to form conglomerate (9)
3 Fruit cut by that man, with new very thin material (8)
4 Two leading characters from quaint English Church cool down by soaking in water (6)
6 Adding an impurity to silicon — phosphorus, indeed! (6)
7 Normalise system performance, partly (6)
8 Derelict building, mostly cold - but it provides insulation (10)
12 Break after short cure, perhaps (8)
13 Easily influenced president to stay in charge (7)
14 Setter's about to enter bar "Royal Compound" (7)
15 Shed tears at last, after breaking high quality glass (7)

Solution to Crossword (May-June 2021)
Across: 7 Password; 9 Check-in; 10 Postman; 11 Inheritance; 15 Latches; 18 Fortran; 19 Home Page
Down: 1 Digerati; 2 Backup; 3 Open source; 4 RSVP; 5 PROMPT; 6 Access; 8 Index; 12 Ethernet; 13 Octet; 14 Python; 16 Turing; 17 E-Bay

QUIZ CLUB, IIT MADRAS

PopScience

Where science intersects with popular culture



1 When Dr Stephen Hawking was writing *A Brief History of Time*, his publisher cautioned him that for every equation included in the book, sales would reduce by half. In the end, Hawking showcased only one equation. Which was it?

2 Which well-known technological word, derived from the Slavic word for "forced feudal labour", was coined in Czech writer Karel Capek's 1920 play *R.U.R. (Rossum's Universal _____)*?

3 In one of the most iconic scenes of a 2010 sci-fi blockbuster movie, a particular physical attribute of one of the characters was designed in a certain manner because it was extremely taxing to figure out its behaviour under the special conditions that were imposed in that scene. For the same reason, the protagonists of a 2014 sci-fi film, by the same director, also had the same attribute designed in a similar (not same) manner for the same reason. Name the movies, the physical attributes, and the specific scenes.

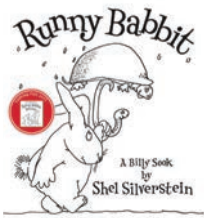
4 The name of company X is said to be a backronym, fusing together the terms "oracle" (intended to mean "a source of truth and wisdom"); "hierarchical" (to describe how X's database was arranged in layers of subcategories); and "officious" (to denote that the company's office workers use X while surfing). The company's founders insisted that the name is derived from a slang word – meaning "rude, unsophisticated, uncouth" – used by the college girlfriend of one of the founders. That meaning derives from the X race of fictional beings from *Gulliver's Travels*. Which company is this?

5 This former roboticist at NASA had an asteroid (that had earlier provisionally been named 1987 DU_8) named after him – for his accomplishments in another domain. In 2013, accepting the honour, he said of the asteroid: "The first thing I did was try to figure out whether (the asteroid) was big enough to pose a threat to Earth. I was excited to learn that, based on its albedo (brightness), it's probably about 6-10 kilometres in diameter. That's comparable in size to the one that killed the dinosaurs—definitely big enough to cause a mass extinction!" Who is this?

PHOTO: RE.PUBLICA

1. $E=mc^2$; 2. Robot, from *robotti*; 3. *Inception* and *Interstellar*; Hair tied in a bun, and short hair; 'zero gravity' scenes; 4. Yahoo!, a backronym of 'Yet Another Hierarchically Organised Oracle'; 5. Randall Munroe, creator of the webcomic *xkcd*.

SPOONERISMS



A **spoonerism** is a pair of phrases that acquire two different meanings when their initial sounds/syllables are interchanged. Find a pair of words/phrases that fit in with the definitions given in the clue such that they have two different meanings when their initial sounds/syllables are interchanged. The numbers in brackets indicate the number of letters in the spoonerism phrase. At least one of the words/phrases has a science/technology theme.
Example: String jumbo chess pieces together, to peruse literature (4,5; 4,5)
Solution: **Bead rooks; read books**

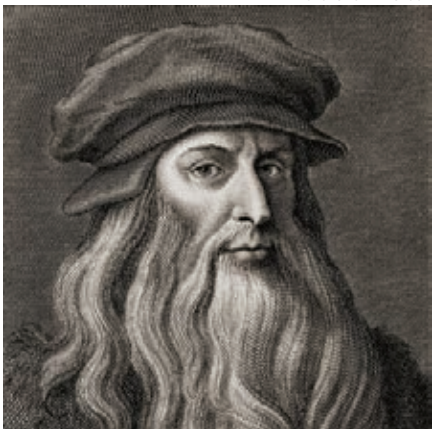
1. Ghost urn for complex numbers, perhaps (7, 4; 6, 5)
2. Put mark without direction (3, 4; 6)
3. Scruff excite, scientific (4, 6; 9)
4. Blacken relish fragment (3, 6; 8)
5. Continue to dress the fifth on the table (4, 2; 5)

IT'S ALL G(R)EEK TO ME!

The given word or phrase or sentence holds two clues: taking away a Greek alphabet from a synonym of the first half yields a synonym of the second half. The numbers in brackets indicate the number of characters in each of the two synonyms.
Example: Letter's wager (8, 3)
Solution: **From the word Alphabet, which is an eight-letter word synonym for Letter, take away the Greek alphabet Alpha, and you're left with Bet, a three-letter word synonym for Wager.**
Alphabet – Alpha = Bet

NOW, CRACK THESE:
1. Sings for dip (6, 4)
2. Containing both letters and numbers or just numbers (12, 7)
3. Selling goods is annoying (9, 6)
4. Type of physics that is understandable (7, 5)
5. High-seas marauder tariff (6, 4)

PHOTO: SHUTTERSTOCK



ANAGRAMS

Scramble the given phrase to get the names of renowned scientists.
Example: Narwhales cried
Solution: **Charles Darwin**

NOW, TAKE A SHOT AT THESE:
1. O, draconian devil!
2. Feral blonde
3. Long demerger
4. Nephew as knight
5. Oh, a barge

1. Spectre vase; Vector space
2. Lay scar; Scalar
3. Neck tickle; Technical
4. Tar pickle; Particle
5. Robe on; Boron

1. Hummus – Mu = Hums; 2. Alphanumeric – Alpha = Numeric; 3. Retailing – Eta = Riling; 4. Nuclear – Nu = Clear; 5. Pirate – Pi = Rate

1. Leonardo Da Vinci
2. Alfred Nobel
3. Gregor Mendel
4. Stephen Hawking
5. Aage Bohr

The floppy disk that revolutionised computing

By making data portable, IBM's 8-inch 'memory disk' may have catalysed the 'personal computer' revolution and contributed to the birth of the software industry.

1971

FLOPPY ART

Floppy disks may no longer serve a functional purpose, but they are being repurposed as recycled art. Creative folks use 5¼-inch floppies as a clock face and as coasters, as spatulas – and even as jewellery or clothing accessories! Still others put them to more traditional use: to update or back up old systems.

NAPKIN NATTER

How did the 5¼-inch disk size come about? There's an apocryphal story that Chinese-American inventor An Wang (of Wang Laboratories) was at a bar with engineers, discussing the size of the disk he wanted. Wang motioned to a cocktail napkin and said he wanted it to be about that size – or about 5¼ inches wide.

SAVE THE ICON

Floppy disks may have gone out of vogue, but their visual representation lingers on – in the 'Save' icon in the toolbars and menus of many computer applications. Even computer users who have never used a floppy disk can intuitively identify the 'Save' icon.

Back in the 1960s, tech giant IBM had a problem. Its mainframe computers systems, which were beginning to cover a range of commercial and scientific applications, faced a peculiar limitation. It was a time when data entry and software programming were still being run on 'punched cards': pieces of stiff paper that held digital data. And although semiconductor control stores were coming into being, they had one drawback: stored information was lost when the power was switched off. Effectively, the operating instructions to run the IBM mainframes were erased. As Alan Shugart, then a product manager at the company, noted, with every restart, the microcode had to be loaded into memory, which was a time- and labour-intensive process.

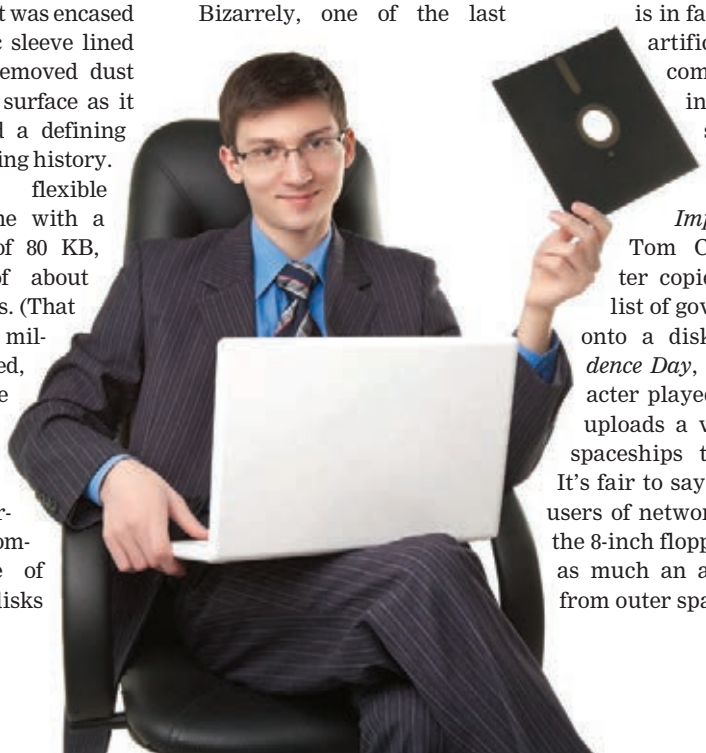
In time for the 1971 launch of IBM's System/370 range of mainframes, Shugart had assigned a design team under engineer David L. Noble to develop a new way to load microcode into the computer systems. The product that Noble's team designed was an 8-inch-diameter flexible "memory disk" that was encased in a square plastic sleeve lined with fabric that removed dust particles from the surface as it rotated. It marked a defining moment in computing history.

The read-only, flexible "floppy disk" came with a storage capacity of 80 KB, the equivalent of about 3,000 punched cards. (That represents many millions of trees saved, which would have otherwise been cut down to make those cards.) And data became portable between computers. The ease of handling floppy disks opened up a world of usage possibilities. More broadly, it is widely acknowledged that the invention of the floppy disk eventually enabled the personal computer revolution, and catalysed the emergence of an independent software industry.

Over time, an echo of Moore's Law – which states that computer processor speeds will double every two years – began to apply to floppy disks, too. They shrank in size, from the original 8 inches to, first, the 5¼-inch format, and then to the 3½-inch disk. By then, the disk had also lost a lot of its 'floppy' nature, but the name remained. Personal computers came equipped with compact floppy disk drives, until Compact Discs became the default program and storage devices. Greater access to the Internet and to cloud storage effectively did away with the need for both disks and discs. In 1998, Apple released an iMac without a floppy drive, claiming that it had become obsolete with expanding hard drive capacity and wider Internet use. Other companies fell in line over time.

Bizarrely, one of the last holdouts was the U.S. Defense Department, which was using 8-inch floppy disks as recently as in 2019 – for command-and-control operations of the country's nuclear arsenal! A 2016 report of the U.S. Government Accountability Office noted that the Strategic Automated Command and Control System (SACCS) ran on an IBM Series/1 computer, and used 8-inch floppies to manage ballistic missiles and nuclear bombers. Evidently, it was felt that since these systems were not connected to the Internet, they were hack-proof. Even so, as part of an overhaul effort to replace outdated software and hardware, ageing SACCS floppy drives were replaced with a "secure solid-state digital storage solution" in June 2019.

In popular culture, as reflected in Hollywood movies, the 8-inch floppy nearly triggered a nuclear war. In the 1983 movie *WarGames*, the gaming character played by Mathew Broderick uses an 8-inch floppy to hack into what he thinks is a video-game company to preview a nuclear-war-themed game, but is in fact a government artificial intelligence computer. The 3½-inch disk, too, surfaced briefly in two 1996 films – *Mission: Impossible*, where Tom Cruise's character copies a Top Secret list of government agents onto a disk; and *Independence Day*, where the character played by Will Smith uploads a virus onto alien spaceships to defeat them. It's fair to say that for today's users of networked computers, the 8-inch floppy will seem just as much an alien as visitors from outer space. •



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