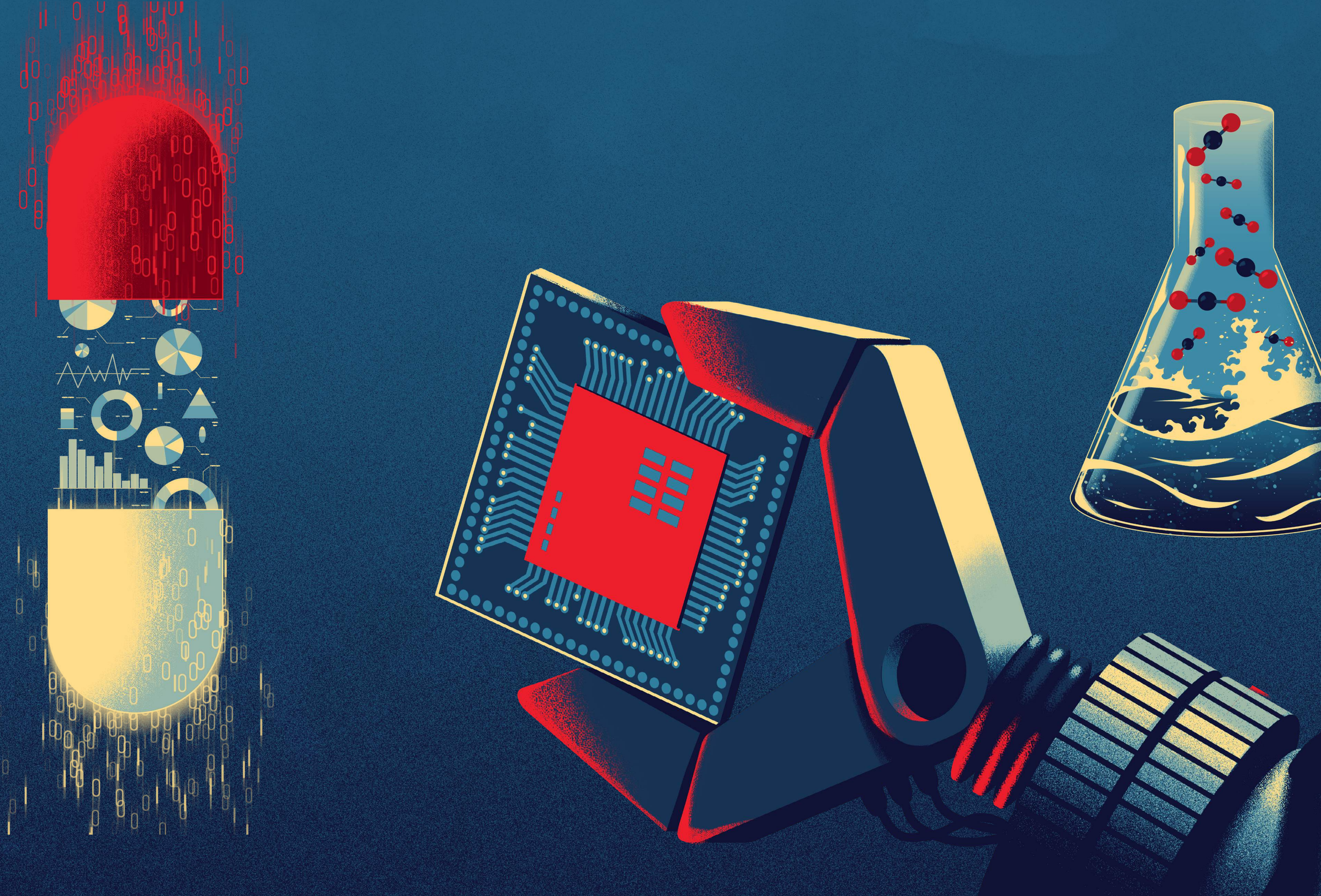

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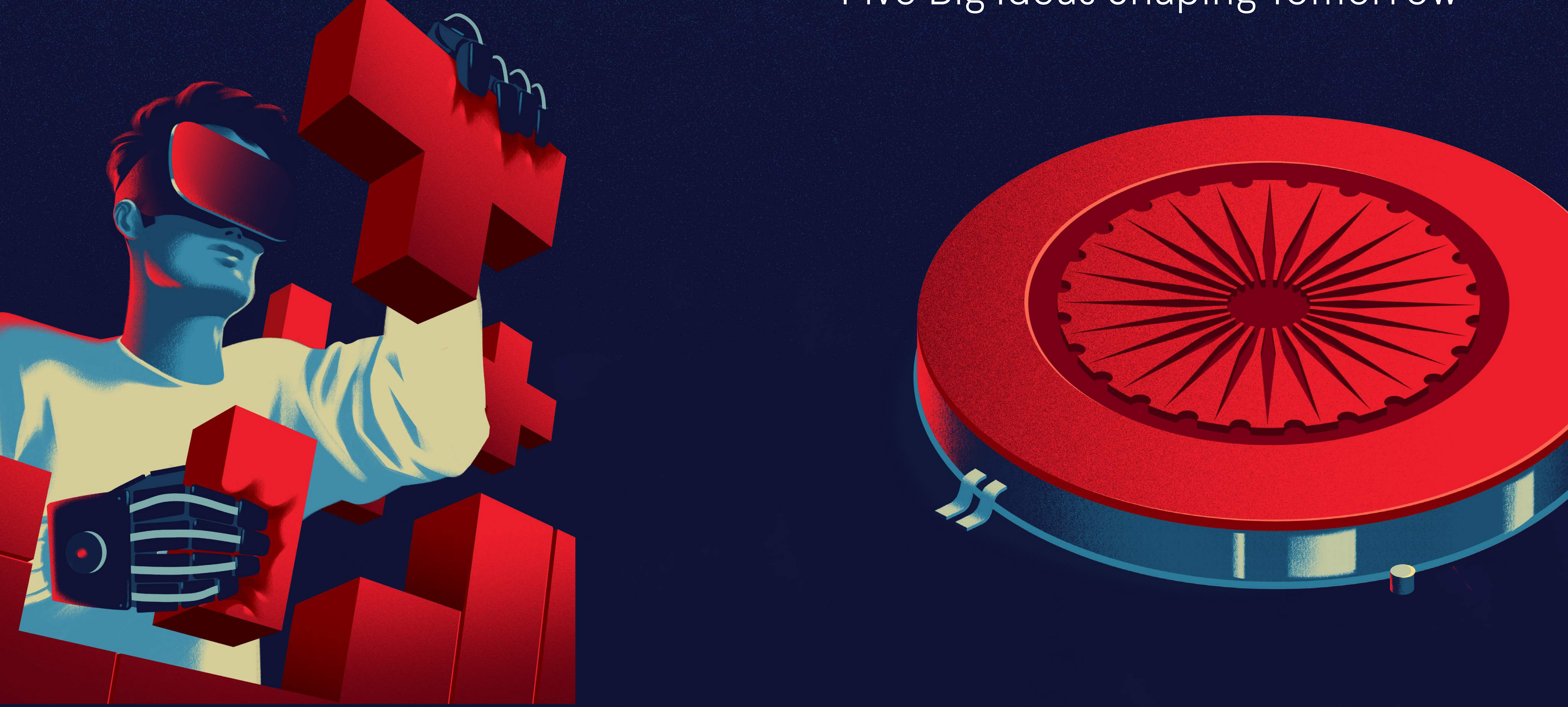
Five Big Ideas Shaping Tomorrow



The world is changing faster than ever.
Next-gen microchips, breakthroughs in AI, accelerating connectivity. A myriad of technological shifts are conspiring to hasten the speed and impact of innovation.

Amid the disruption, it can be difficult to discern what matters. What's merely hype or hyperbole, and what are the signals of change that are worth tracking?

That's where Frontiers comes in.

This isn't an exercise in black-and-white predictions, which are largely a fool's errand. The annals of futurology are shot through with forecasts that either wildly underestimate or overestimate what's to come (any news on those jet-packs?). Frontiers aims to take a more nuanced approach, and considers possible futures by looking at what's happening in the here and now.

It's easier to see the larger tectonic shifts: we're confident that climate tech is going to remain important, for instance, so too the space economy. But within the broader trends such as those, what are the cutting-edge micro-trends that could become increasingly interesting?

We have shone a light on five nascent ideas that share a few common characteristics. All of them are enjoying serious venture capital flows and all of them attempt to solve genuine problems. What's more, they are attracting attention from credible experts. For each story we've interviewed one of them, to hear why they're excited but also what challenges still need to be solved.

These ideas are:

"These ideas aren't science fiction—they are real things, and they're starting to happen right now. One group that should be following these developments is investors. While it may not be straightforward to get direct exposure to the specific area, investors need to consider investing in the underlying trend," says Willem Sels, Global CIO of HSBC Global Private Banking. "The question is how these ideas evolve from here—but if they do take hold, then they could change our world for the better."

HOW FACTORIES IN SPACE COULD SOLVE PROBLEMS ON EARTH

Remove gravity and new manufacturing possibilities are unlocked

L

ight a candle on Earth and the flame points upwards. But in space, the fire blazes in all directions equally, causing a slow-burning globe of combustion. The difference is gravity, which fundamentally changes how atoms and molecules behave.

So, why not leave it behind to manufacture revolutionary materials and overcome roadblocks in a range of innovations? That's the thinking of a number of ambitious startups who have raised significant venture capital to achieve just that.

Varda Space Industries, a company founded in 2020 by SpaceX veteran Will Bruey and Founders Fund partner Delian Asparouhov, is one of them. It has acquired $54m in funding to create an automated manufacturing facility, which fits inside of a spacecraft that contains its own reentry vehicle. "We have a fundamentally unique way of manipulating chemical systems that physically cannot be done on Earth, because gravity is a fundamental force," says Bruey. "That's the source of our value."

Until recently, space was the domain of public agencies with big budgets. But, as the costs of manufacturing, launching, and operating satellites have fallen, thousands of private companies have launched their own space programs in the name of scientific advancement and business opportunity. The space economy, meaning the value of goods and services that comprise the commercial

"THE SPACE ECONOMY IS PREDICTED TO REACH OVER $737 BILLION WITHIN THE NEXT DECADE."

space sector, grew eight percent last year to reach $464 billion, according to Euroconsult's Space Economy Report. The authors predict that its value will reach over $737 billion within a decade.

One segment of this is off-planet manufacturing, which has traditionally been discussed in the context of reducing our greenhouse gas emissions. Varda, however, is one of several companies pursuing it because the hyper-clean, microgravity conditions of space provide a near-perfect environment for manufacturing certain specialist materials, including fiber optics and semiconductors, because it allows for fabrication with fewer impurities and defects.

This nascent industry wants to build on research carried out at the International Space Station (ISS), which has underlined the potential of off-planet manufacturing. These projects have been expensive and small-scale, because they require astronauts to actually carry out the tests. But the dual trends of falling launch costs and increasingly sophisticated robotics offer a path to accessibility. "It's about taking what the science has proven and allowing commercial customers to scale that up," says Asparouhov.

Initially, Varda will focus on manufacturing pharmaceuticals. Microgravity is especially useful in developing the dosage form of a drug, where the active chemical ingredient is formulated into a pill, injectable, or other product that can be safely administered to patients. This is where constraints often arise. Medicines that would be easier to take as a pill may only be successfully delivered as an injection, for instance—and in many cases effective molecules fail to lack a viable formulation. "Even though they know it will be able to cure the disease," says Asparouhov, "there is no way to practically bring it to market."

Without gravity's pull, however, you can formulate many drugs in new, more patient-compliant versions. It's not just about the form of the drug; it's also about dosage. Instead of taking five pills a week, you might be able to take just one. Microgravity manufacturing may also reignite the development of a whole catalog of effective but forgotten drugs whose development has stalled on Earth.

In June, Varda launched its first of four demonstration missions, aiming to show that the automated hardware

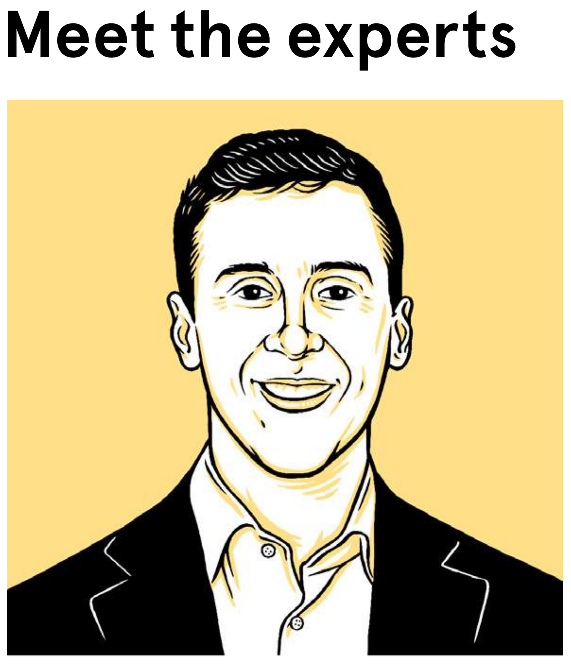
"GETTING TO SPACE IS OLD NEWS. WHAT YOU DO WHEN YOU'RE OUT THERE IS WHAT COUNTS."

Delian Asparouhov, co-founder at Varda Space Industries and chemical processes actually work. In this mission, the company's spacecraft was sent to low Earth orbit on a SpaceX ride-share, before executing a process of heating and cooling. The spacecraft will be returning to Earth via parachute in July. In the future, the company's space capsule will be sent into low Earth orbit, before executing a process of heating, cooling, and mixing, and then returning to Earth.

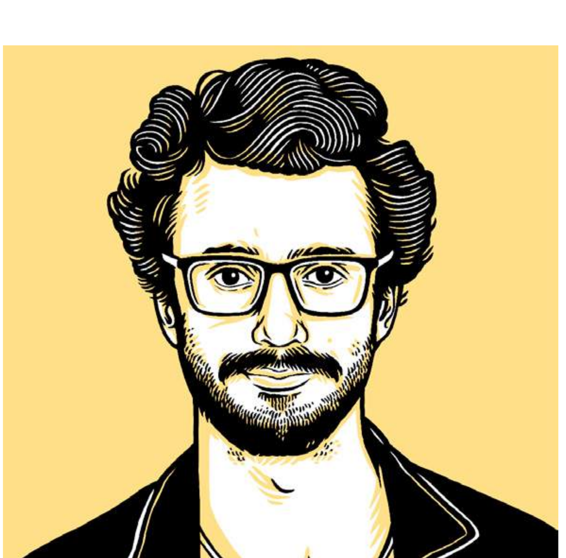
It's a risk-laden project, and proof of concept alone would be a significant achievement. But in true Silicon Valley style, the company has a bullish vision that stretches decades ahead. Within five years, Varda hopes to have hundreds of automated manufacturing facilities orbiting Earth. Once spaceflight costs have fallen sufficiently, the company plans to turn its attention to computer chips, fiber-optic cables, and semiconductors. Eventually, Varda wants to build the first manned space factory, which will orbit the Earth with thousands of humans on board.

"Getting to space in old news," Asparouhov says. "What you do when you're out there is what counts."

Meet the experts



William Bruey
is the CEO at Varda Space Industries, which has launched and is operating its own self-sustained space factory in orbit.



Delian Asparouhov
is a partner at Founders Fund and co-founder and President of Varda Space Industries, which is building the world's first space factories.

WHY TOUCH IS VR'S MISSING INGREDIENT

A burgeoning haptics sector wants to solve the tactility problem

V

irtual reality has been the next big thing for decades. The appeal isn't hard to understand: the ability to strap on a headset and dive into a different world has the potential to transform everything from retail to entertainment. But while the field has developed considerably over the past ten years, it continues to struggle in the mainstream.

VR is beset by challenges. The headsets remain clunky and expensive; there are still technical problems to solve; and the marketplace has certainly not been helped by a dearth of content. But to Dr. Bob Crockett, co-founder of haptics company HaptX and Professor of Biomedical Engineering at California Polytechnic State University, there's another more fundamental reason: VR doesn't sufficiently seize control of the user's senses. "Even with modern headsets, which have a resolution close to what the eye can detect and a field of vision that goes beyond your line of sight, it's not immersive enough," he says.

That's precisely where haptics—which adds touch to virtual experiences by applying forces, vibrations, or motions—comes in.

You've already experienced this technology. When your phone gives you force-feedback as you press a key on its touchscreen, or when your smartwatch taps your wrist to alert you to an incoming message—that's haptics.

But it also encompasses more sophisticated, emerging wearables that can simulate everything from the experience

"EVEN WITH MODERN HEADSETS… VR IS NOT IMMERSIVE ENOUGH"

Dr. Bob Crockett, co-founder of HaptX and Professor of Biomedical Engineering of holding an apple to shaking somebody's hand. Activity in this space reignited in tandem with the conversation around the "metaverse"—a report by Verified Market Research last year forecast that the global haptics market would grow by 12.1 percent annually to hit $6.2bn by 2028.

A number of headline-grabbing startups have duly emerged. One of the most high profile is Crockett's HaptX, which has raised $59.5m, of which $23m came in September alone, to develop a range of lightweight, wireless haptics gloves geared towards industrial and academic applications. Major automakers use them for designing systems in virtual reality, while the U.S. army uses them for field-medic training.

"Haptics is not just the enabling technology for any truly immersive experience," says Crockett. "It's the dividing line between virtual reality as interesting, and virtual reality as truly impactful."

Whereas most haptics companies use electronic actuators that essentially vibrate on top of the skin, HaptX's approach is all about pressure. Each glove comprises pneumatic exotendons, which brake the fingers' movement, and 133 tiny balloons that inflate or deflate on the underside of the palm and fingertips.

While this system allows for rapid, high-resolution sensations, the big challenge is the cost. Off-the-shelf components are not up to the task, so the company currently develops its own pneumatic circuitry. A pair of HaptX gloves is commensurately expensive, costing $5,495. "A system built on pneumatics is inherently complex, but pneumatics is still the best technology for realistic haptics that is scalable across the entire body," Crockett says. Within the next decade, Crockett expects to see consumer deployment of high-quality haptics such as this happening at physical VR entertainment centers. After that, as the technology becomes more affordable, it may filter into private homes.

During this transition, Crockett believes the range of hardware produced by the haptics industry will grow, because we need more than gloves and vision to create full immersion. One day, he believes we can expect full body systems that also simulate terrain, enabling a user to move about in a virtual world with tactile verisimilitude.

"RESEARCH LAST YEAR FORECAST THAT THE GLOBAL HAPTICS MARKET WOULD GROW BY 12.1 PERCENT ANNUALLY TO HIT $6.2 BILLION BY 2028."

The applications could span everything from controlling humanoid robots in dangerous environments to the performance of a range of remote healthcare tasks. “Given the tremendous, global shortage of registered nurses, the ability to support the development and use of remotely controlled, healthcare-support robots really inspires our team,” he says.

To get to that point, though, he believes the consumer market needs to catch fire—and that depends on big players in gaming and Hollywood creating better haptics-enabled content. “Because as great as virtual worlds in which we can touch and feel objects might sound,” says Crockett, “nobody is going to spend time in them unless there’s a compelling reason to do so.”

Meet the expert

Dr. Bob Crockett
is a Professor in Biomedical Engineering at California Polytechnic State University and co-founder of X-Lab for HaptX, Inc.

HARNESSING THE OCEANS COULD HELP FIGHT CLIMATE CHANGE

Their potential for carbon capture is huge—but so are the unknowns...

W

ater covers 70 percent of our planet, but you probably already knew that. What fewer people are aware of is that our oceans absorb around one quarter of human-made carbon dioxide emissions. To put it another way, the ocean is already our largest carbon sink—and it could potentially be leveraged to pull even more CO_2 out of the air and safely store it. But first there are some important questions to answer.

"Doing projects on land is the obvious place to look first when we're trying to remove carbon, and the ocean is the next frontier," says Katie Lebling, an associate in the World Resources Institute's (WRI) Climate Program, who recently authored a WRI report looking at responsibly scaling up ocean carbon dioxide removal.

Indeed, huge amounts of resources are being invested in direct air capture and storage technologies that actively extract CO_2 from the atmosphere and store it elsewhere, such as underground or in new materials. But this process is expensive and energy intensive today. Combined with the need to develop a range of carbon removal options, this has led to a growing focus on removing CO_2 via our oceans. Already, Lebling says, tens of millions of dollars are being invested in nascent technologies that aim to do just this. A raft of startups are emerging, some boasting high-profile corporate investors and partners.

Fundamentally, all ocean-based carbon dioxide removal

"OUR OCEANS ABSORB AROUND ONE QUARTER OF HUMAN-MADE CO_2 EMISSIONS."

approaches tap into the natural ocean processes that absorb CO_2 from the atmosphere. Once the dissolved carbon dioxide from the seawater is removed through biological or chemical processes, the oceans suck additional CO_2 from the atmosphere to replace it.

There are dozens of ways to enhance or accelerate this. One category of approaches is biotic, which covers those that rely on cultivating photosynthesizing organisms such as seaweed to store the dissolved carbon dioxide as biomass. By adding nutrients to the ocean (a process called "ocean fertilization") or moving deeper, nutrient-rich water to the surface ("artificial upwelling"), climate scientists can increase the population of phytoplankton that take up dissolved CO_2.

Then there are abiotic approaches, which are about changing the ocean's physical or chemical properties. One option is to add alkaline minerals to ocean water, which react with dissolved CO_2 and lock it away as a solid carbonate—a process known as alkalinity enhancement. Another type of approach, electrochemical extraction of CO_2, is receiving particular interest right now. Electrodialysis involves passing water between two plates before applying electricity to convert bicarbonates in the water to molecules of CO_2. These can then be removed under vacuum conditions and either buried under the sea floor or converted into specialized chemicals such as synthetic fuel. The concentration of carbon dioxide in seawater is more than a hundred times greater than in air per unit volume, so electrodialysis has the potential to be more efficient compared to direct air capture. Whether it uses less energy overall, though, is unclear.

As with alkalinity enhancement, one further benefit of electrodialysis is that it could help reduce acidification. When CO_2 dissolves in seawater, the water becomes more acidic which negatively impacts marine creatures with shells and skeletons of calcium carbonate, because these more readily dissolve in acidic conditions. Shellfish, urchins, corals, and plankton suffer, as do some fish who find it harder to detect predators. By reinjecting alkaline water, electrodialysis can slowly start to reverse this effect, at least locally.

But while ocean carbon removal approaches provide

"IF WE ARE ABLE TO START MAKING THESE INVESTMENTS TODAY… IT COULD REALLY PAY OFF IN THE COMING DECADES."

Katie Lebling, associate in the World Resources Institute's Climate Program huge potential, they present "a whole set of new risks and uncertainties", says Lebling. For instance, it's unclear how they will affect ocean ecosystems in the long term. "We have such a low level of understanding about the ocean," she continues. "Ecological and environmental impacts can show up a year after you do the project. They can show up in a different location. So it can be really hard to tell what impact they're having."

As much as there's a tendency to be more accepting of approaches that seem more natural, like growing seaweed, it's important to understand that these also pose ecological and environmental risks depending on the scale and location of their implementation, among other factors.

There are also questions around the efficacy of these approaches. The ocean's ability to draw CO_2 from the atmosphere relies on Henry's Law, which says that there must be an equilibrium between the atmospheric concentration of a gas and its concentration in the ocean.

"Still, though, there are a lot of questions about how long that equilibrium takes, and how that changes in different locations," says Lebling. "If the ocean water circulates so the CO_2-depleted water moves down and it doesn't equilibrate, then there hasn't been any CO_2 removed from the air."

To resolve these uncertainties is going to take time and more investment in research. "But if we are able to start making these investments today," says Lebling, "it could really pay off in the coming decades."

Meet the expert

Katie Lebling is an Associate in the World Resources Institute's Climate Program working on research and analysis of technological carbon removal approaches and industrial decarbonisation.

GENERATIVE AI WILL TRANSFORM MEDICINE

The new wave of AI tools are about far more than text and images

Imagine a world in which we can develop new drugs to treat diseases in a matter of months, rather than years. Where we can slow down or even nullify conditions once believed to be untreatable. Because of new developments in AI, this might soon be possible. That's according to Anima Anandkumar, senior director of AI research at NVIDIA and the Bren Professor of Computing at California Institute of Technology.

"This is an inflection point for the use of AI in life sciences," she says. "Gartner predicted that by 2025 more than 30 percent of new drugs and materials will be systematically discovered using generative AI techniques, up from zero today. I believe we will meet or even exceed this prediction."

> **"IT'S PREDICTED THAT BY 2025 MORE THAN 30 PERCENT OF NEW DRUGS AND MATERIALS WILL BE SYSTEMATICALLY DISCOVERED USING GENERATIVE AI TECHNIQUES."**
>
> Anima Anandkumar, senior director of AI research at NVIDIA and the Bren Professor of Computing at California Institute of Technology

The field of AI has been enjoying a boom phase for a decade thanks to advancements in machine learning. Most of those developments have been related to making sense of existing data, identifying patterns, and extrapolating insights. Recently, however, there have been breakthroughs in generative AI models. These produce new content altogether. Instead of simply recognizing a face in a crowd, for instance, generative AI can fabricate a new one.

Since December 2022, the technology news cycle has been dominated by gen-AI applications such as ChatGPT, a chatbot that quickly became the fastest-growing consumer application in history. But tools that can produce text and images are only part of a larger wave of gen-AI use cases.

Computer scientists are particularly excited about what gen-AI means for medicine. On the one hand, it could help tackle future pandemics. As easily as you can teach these models English and ask them to generate plausible sentences, you can train them on the genome data of known viruses and ask them to conjure variants of concern before they emerge. "We can use this information to prepare vaccines and other countermeasures before we even encounter them in the wild," says Anandkumar.

But it's on the treatment side that gen-AI holds especially transformative potential—and not just for pandemics. Drug design is an industry that's projected to hit $161.76 billion by 2030, according to Precedence Research. The traditional methodology is convoluted and painstaking. It begins with identifying a biological target, which is usually a protein that is causing a disease process. Next, you must develop a compound that produces the desired cellular effect on that target: either change how it works or shut it down. For a compound to be effective, it must also bind with the target—but because the target receptor's structure morphs when it binds, this is no easy task to accomplish.

Traditionally, chemists begin by sifting through libraries of existing compounds to synthesize and test in a laboratory. They'll modify each promising compound, adding and removing atoms based on its effectiveness. It can take thousands of iterations and years of work before a candidate can even be tested on humans—and many of them still fail because of how they interact with the body as a whole. "There are so many steps to the process," says Anandkumar. "With every one it becomes more expensive."

AI offers a welcome shortcut. By crunching masses of data, such as the structure of pathogens and the efficacy of existing drugs, gen-AI models can produce drug molecules that are fit for purpose and may never have been seen before. These can then be synthesized to spec. In other words, rather than looking for the needle in the haystack, you simply create the needle.

Anandkumar herself is exploring this space with her

"IT MAY BECOME ECONOMICALLY FEASIBLE TO DISCOVER NEW AND BETTER DRUG MOLECULES BASED ON SPECIFIC TARGETS IN A PERSON, ACCORDING TO THEIR GENETIC ANALYSIS."

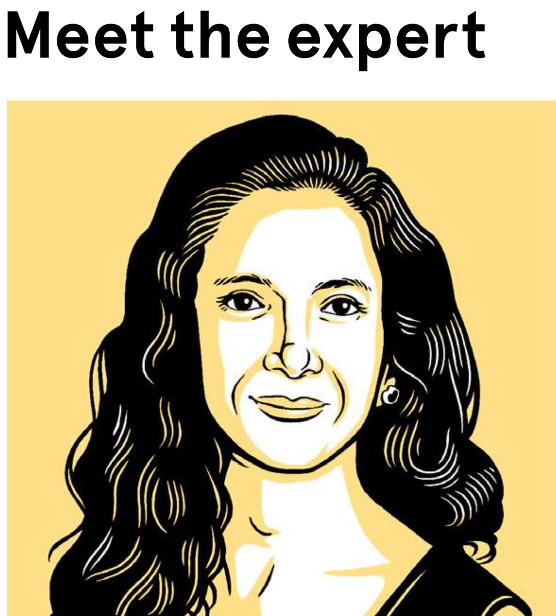
Anima Anandkumar, senior director of AI research at NVIDIA and the Bren Professor of Computing at California Institute of Technology colleagues at Caltech and NVIDIA, and in collaboration with public research centers such as Argonne National Lab and the pharmaceutical company Entos. The latter is one of a raft of startups and incumbents in the medical sector who are putting gen-AI tools front and center.

Over the next decade, she expects to see these models producing drugs that are personally tailored to the patient. "Once the drug design cycle gets vastly sped up and cheaper," she says, "it may become economically feasible to discover new and better drug molecules based on specific targets in a person, according to their genetic analysis."

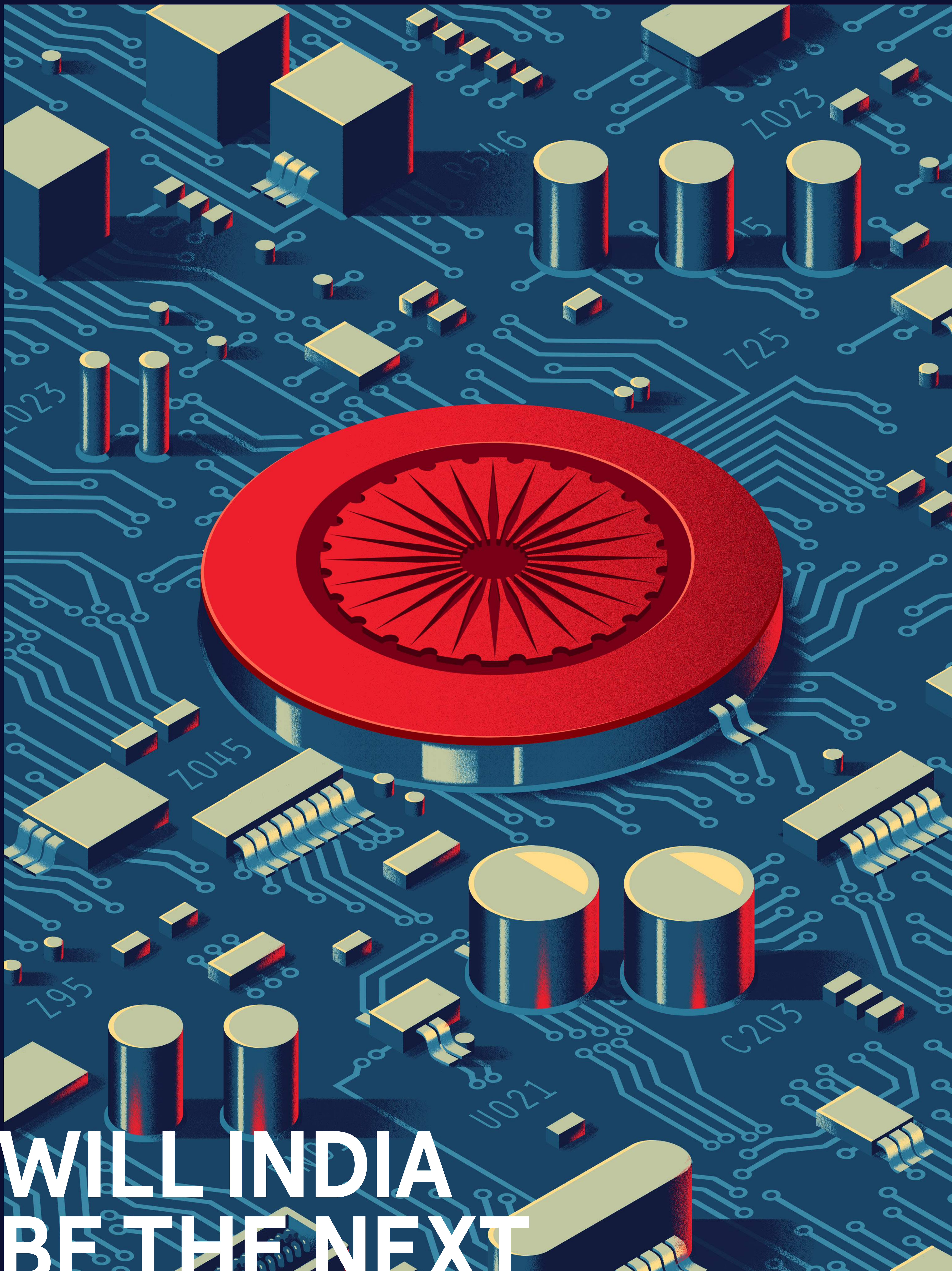
The major hurdle, though, is data. These algorithms are only as useful as the data they're trained on. Gen-AI has been successful in applications such as text and image generation because there's a wealth of historical, valid data accessible. But in fields such as the study of molecular properties, says Anandkumar, the data is more limited or even unavailable.

She believes that the solution may lie in physics-informed learning, where you embed physical laws and boundaries in the model's processes. "Training models to follow those rules makes them significantly more powerful and accurate," she says. This could unlock their industrial potential not only in drug design but well beyond. "We need a foundation AI model for science and engineering that understands complex phenomena beyond just text or natural images," she continues, "and I believe we will see such developments in the near future."

Meet the expert



Anima Anandkumar is Bren Professor at Caltech and senior director of AI Research at NVIDIA where she develops novel AI algorithms and applies them to a broad range of scientific domains.



WILL INDIA BE THE NEXT SEMICONDUCTOR SUPERPOWER?

If its chip-making gamble pays off, it could bring a global boost

D

o you remember the semiconductor shortage of 2021? When automakers were forced to stall their vehicle production, and electronics manufacturers had to delay product launches?

Well, if India makes good on its ambitions to become a superpower for microchip design and development, it will ensure that in the future we're more resilient.

That's the opinion of Sarah E. Kreps, the John L. Wetherill Professor of Government and director of the Tech Policy Institute at Cornell University. "Now is the perfect opportunity for India to take advantage of something that it has long had, but been unable to capitalize on," she says of India's English-speaking engineering talent. "Before now, other semiconductor hubs in Asia have been able to meet the demand."

"NOW IS THE PERFECT OPPORTUNITY FOR INDIA TO TAKE ADVANTAGE OF SOMETHING THAT IT HAS LONG HAD, BUT BEEN UNABLE TO CAPITALIZE ON."

Sarah E. Kreps, John L. Wetherill Professor of Government and director of the Tech Policy Institute at Cornell University

Microchips—often known as semiconductors—are the brains behind electronic devices, from laptops and refrigerators to mobile phones and, yes, cars. The industry, which is worth more than $580bn (£466bn), has been dominated by China, South Korea, and Taiwan, who manufacture microchips in specialized "foundries" on behalf of companies all over the world. But over-reliance on imports from a handful of chip-makers leaves global supply in a precarious position.

This is especially true in times of geopolitical uncertainty, like now. In response, countries have been making moves to boost their domestic chip-making industry. In August, President Biden's administration signed the CHIPS and Science Act, representing an injection of $52.7 billion into the sector. But domestic manufacturing is expensive. By one estimate, making chips in the US would cost 55 percent more.

This has created a demand for an alternative hub for affordable and dependable semiconductor production, and India is emerging as a front-runner. It has a large geographic size and it has historically taken a non-aligned political position. "It's close enough to Asia without being vulnerable to the same perceived security risks that the East Asian chip powerhouses face," says Kreps.

The country also boasts a rich technology sector, which will grow 8.4 percent to $245 billion this fiscal year, according to a NASSCOM report. This transformation dates back to the 1990s, when India emerged as a global IT outsourcing powerhouse thanks to its low-cost labor and a shared language in English, but the country has since cultivated an ecosystem of startups and home-grown tech unicorns. "Where you want resilience in your supply chain, a politically and economically friendly climate, a low cost of labor—India is extremely well positioned for that," Kreps continues.

Spotting the opportunity presented by this geopolitical moment, India has been making moves to bring the manufacturing of chips to the country. In December 2021, officials approved a $10 billion incentive plan to lure domestic and international foreign semiconductor manufacturers, under which the government will return 50 percent of the upfront capital back as a rebate. On January 31, US President Joe Biden and Indian Prime Minister Narendra Modi unveiled the United States-India initiative on Critical and Emerging Technologies aiming to catalyze existing efforts at technology cooperation.

These moves seem to be having the desired effect. India has since won ten of billions of dollars of investment commitments from major chip consortia and manufacturers.

Still, the challenges that lie ahead shouldn't be ignored. Conjuring a thoroughgoing, competitive chip-making industry will be no mean feat. For one, India does suffer from poor infrastructure, which could pose a barrier

"IN DECEMBER 2021, OFFICIALS APPROVED A $10 BILLION INCENTIVE PLAN TO LURE DOMESTIC AND INTERNATIONAL FOREIGN SEMICONDUCTOR MANUFACTURERS."

specifically when it comes to manufacturing processes. This requires uninterrupted electricity and massive quantities of ultra-pure water, and given the country's acute power crisis and droughts, managing these huge plants might be a problem.

According to Kreps, though, these impediments aren't insurmountable. Before they became semiconductor manufacturing hubs, Taiwan and South Korea were in a not dissimilar position to where India is today. "Per capita income was $100, many people had to forage for food, and living conditions were spartan," Kreps says. But their economies transformed and India can do the same. "We think about South Korea and Taiwan as having the pristine conditions necessary for finessing the semiconductor chip business, but they were not always how we see them now," she says. "And just as they've changed over the last decades, so too could India."

Meet the expert

Sarah Kreps
is the John L. Wetherill Professor and director of the Tech Policy Institute at Cornell University.

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