OVER THE HORIZON

What scientific and technological milestones can we envision 50, 100 and 150 years hence? Each month we have the luxury of being able to look back into the past, to what people were writing 50, 100 and 150 years ago. We can do this because Scientific American has put its readers at the forefront of science and technology for more than 167 years. To mention just one example, our October 1962 issue featured Francis Crick, co-discoverer of the structure of DNA, explaining the meaning of this wondrous molecule, and psychologist Leon Festinger writing on what he meant by the term “cognitive dissonance.” A strong past is a good foundation from which to look into the future. In that spirit, we asked our authors to train their imaginations on what the world might look like 50, 100 and 150 years from now. Will cars fly? Will we still have computers, and if so, what will they do? Will nuclear weapons be banished? Will our technology save us from a changing climate or make things worse? What is the fate of tigers and other wild creatures on an increasingly crowded planet? To what extent will we master our genes to stave off disease? And if we ever leave this planet, how will the journey change us? In the following pages, you will find answers. Not the answers—we are not making predictions but rather doing thought experiments, grounded in science fact, with an eye to illuminating today’s world and provoking thought about what comes next.

—The Editors

When the U.S. Civil Aeronautics Administration certified the Aerocar for operation in 1956, it seemed inevitable, at least to aerospace engineers, that before long the flying car would take its place as a fixture in the garage of the typical suburban ranch home. Yet that was not to be. The Aerocar, which looked like a car but had wings and could take off on a short runway, was too expensive to justify mass production. Aerocar International built only six of these vehicles, leaving the promise of the flying car unfulfilled—except in episodes of The Jetsons.

More than 50 years later the flying car is making a comeback. Two models have completed one or more flight tests. The Transition, built by Terrafugia in Woburn, Mass., is a Light-Sport aircraft with foldable wings that can carry two people, plus luggage. To fly, you first need to drive it to an airport (it requires a conventional runway). The PAL-V ONE (for personal air and land vehicle), built by PAL-V Europe in Raamsdonksveer, the Netherlands, needs only a little more than 650 feet to take off. It looks like a three-wheeler crossed with a helicopter. Thrust comes from a rear-mounted propeller, and a free-spinning rotor on the top generates lift. Both cars cruise below 100 knots and have a decent range on a tank of fuel (450 miles for the Transition; about a third lower for the maximum range of the PAL-V).

Neither car, however, is going to fulfill the promise of bringing flying vehicles to the masses. Even if the manufacturers were able to bring down the anticipated $300,000 price tag for both to more affordable levels, the market is limited because of the prospect of hordes of private aircraft going from road to air and back. Airports have enough trouble today coordinating the comings and goings of a few thousand jets. If every car could fly, the skies would be in chaos.

Currently pilots of flying cars can take advantage of the relatively new Light-Sport category; these aircraft can be flown by any-
A DRONE IN EVERY DRIVEWAY

The only way to bring flying cars to the masses is to leave the flying to the car

By Mary Cummings

one with a valid driver’s license, no major medical conditions and a Sport Pilot certificate (which includes a requirement of only 20 hours of training). The Sport Pilot category keeps pilots out of congested airspace, for good reason, and limits operations to personal use: no business can be conducted under this license.

This method of certification works only because there are relatively few people who fly their own personal vehicles. If drivers were to take to the skies in significant numbers, the congestion would become dangerous. Flying cars will continue to service small niche markets until they can be truly integrated into the national airspace.

To achieve the kind of transportation breakthrough that will lead to a plane in every driveway, we must let go of our need for control and let the plane do the flying for us. Personal and commercial air vehicles will have to be more like unmanned aerial vehicles (UAVs), or drones.

In the military, personnel who are not certified pilots operate drones. Indeed, one of the most attractive qualities of drones is that they save the military from having to devote a great deal of resources to training pilots.

Drones today have enough smarts in them to go where they are commanded, and research now under way will endow them with enough human-like reasoning to be able to respond to emergency situations on their own. This same vision is behind Google’s robotic car. And given the problems with driver distraction and our predilection to talk, text and eat while driving (and flying), a car that both drives and flies itself may mean safer transportation in the future.

Many technological challenges stand in the way of achieving this vision of a commercially available and economically viable passenger-carrying drone. We will have to establish reliable and safe communications networks and robust autonomous flight controls to guide flying cars along their airborne routes.

We will also have to integrate these operations as part of the national air-traffic-control network—perhaps the most formidable obstacle to creating a nationwide personal air-transport system, given that numerous attempts at overhauling the present air-traffic system have been stymied repeatedly. The basic technology building blocks are there, however. Recent experience with controlling the operation of drones around the globe may provide a model for personal air travel five decades hence. Now we have to figure out how to put all the technological pieces together.

In 2010 the Defense Advanced Research Projects Agency started a program, called Transformer, to build a four-person road-worthy vehicle capable of vertical takeoff and landing—essentially a passenger-carrying drone—that a typical soldier with no aviation background can operate even more easily than existing drone technologies. DARPA expects to fly a prototype during the next few years. With this progress in drone technology, together with commercial personal aircraft such as the Transition and PAL-V—the most advanced implementation of air-road vehicle technology to date—we may well see within the next 50 years the vision of an airplane in every driveway. The George Jetson of 50 years from now will be riding in a drone.

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THE NUCLEAR QUESTION

If the world can’t manage to cast off the ultimate weapons by the middle of the century, we may face extinction

By Ron Rosenbaum

AS WE LOOK BACK FROM THE PERSPECTIVE OF NDDD—Nuclear Disarmament Decision Day on August 8, 2063—it is still not clear how the first “small” nuclear war started in 2024. Yet it is clear that once it happened, things changed. The survivors saw that nuclear war was no longer a fantasy; nuclear extinction the next time was no longer an impossibility. The reality sunk in that deterrence could fail, accidents could happen, terrorists could steal warheads. A nuclear bomb with no return address could be detonated and start a conflagration. A billion people could die.

Nuclear disarmament was the only way to cast off what seemed otherwise inevitable. If there were a next time, it would mean a planetary “extinction event.”

More than half a century ago a group of nuclear strategists (even Henry Kissinger) broke from tradition and surprised colleagues by calling for total worldwide abolition of nuclear weapons, or, as it was eventually known, “nuclear zero.” It had taken more than 50 years. Yet now, at last, everything was in place, to decide in the next few minutes whether it would really happen.

The process for the Final Disposition, as it had come to be called over the past decade, had been worked out in excruciating detail—including all the inspection and enforcement protocols—so that it would be complete, total and simultaneous—so that no one could hang back, hold on to and use their remaining nukes to reign supreme over credulous disarmed nations.

Yet there were still “unknown unknowns” to contend with. Would it be foolproof? Could all parties be trusted? Had some bomb-grade nuclear material escaped even the highly advanced global satellite surveillance and detection system? Had one or more nations disassembled their nukes in such a way they would be ready to reconstruct the separate elements of a nuclear arsenal—the feared “breakout” scenario?

All the known nuclear nations had reduced their arsenals to a bare minimum by 2063. The time had come for what the tablets were calling “the final throw-in,” in which the known nuclear nations would dismantle, destroy and dispose of all their remaining nuclear weapons in a carefully monitored simultaneous moment.

Back in 2011 a pessimist had written, “The only way the world is likely to wake up and realize it can’t live with nuclear weapons would be something that would change human character, perhaps even a small (if we’re lucky) nuclear war.”

We got the war. We were “lucky”—it was (relatively) small. But had human character changed enough?

As the hour approached, and all the screens in the world were focused on the Final Conference Console and the heads of the (known) nuclear states took their seats, some in attendance looked back on the milestones of the past half a century that led to this moment. A chronologist would begin with:

February 5, 2018: The nuclear arms-reduction provisions of the New Strategic Arms Reduction Treaty (New START Treaty), ratified in 2011, between the U.S. and the Russian Federation had finally been fulfilled, thus bringing the number of warheads down to 1,550 on each side.

Yet efforts to negotiate a new round of reductions that would include the other known nuclear states failed over issues such as the importance of antiballistic missile systems, the dream of a satellite-based “Star Wars” system kept alive by the anti-START hawks in the U.S. Senate and the anti-START hawks in Russia’s Ministry of Defense who wanted to build a new generation of multiple warhead missiles. And new nations continued to seek to build their own capacity.

Instead of seeking a new round of treaty reductions or negotiating alert-time reductions to take silo-based missiles off what was effectively “hair trigger,” “use it or lose it,” “launch on warning” postures prone to “inadvertence”—accidental nuclear alerts and war—the two leading nuclear nations devoted themselves to spending billions on antiballistic missile shields. Such unproved deterrents included nuclear-armed satellites and “satellite killers”: for the U.S., in eastern Europe; for Russia, in the Arctic.

August 8, 2021: One of the most feared scenarios occurred on a date chosen for symbolic reasons: “Anonymous 4.0,” the elite, international, anarchist “black hat” collective, hacked into the command and control systems for a nuclear missile silo in Montana and another on the frozen wastes of the Vladivostok peninsula.

One missile launched from each locale. Nobody knew if they had detonation codes until both missiles landed in the “sea of garbage,” an area the size of Texas in the Pacific’s northern reaches, and failed to detonate. More troubling: satellite-launched anti-missile interceptors missed hitting them by miles. The result was that no nation could now tell whether to trust the integrity of their all-important C3 (Command, Control and Communications) tech.

A cyber sword of Damocles was hanging over the world.

August 2024: The sword fell. Everyone thought it would be China/Taiwan, Iran/Israel or North Korea/South Korea. Yet after several extremely close calls earlier in the century, it finally happened: India/Pakistan. A nuclear bomb with no return address (except for an untraceable e-mail whose veracity was never determined) was detonated in Mumbai, and the Indian government chose to blame a Pakistani terrorist group, which led both sides to decide to preempt the other’s preemption.

At last we knew what it would be like.
And it was worse than could have been imagined. People were shocked to the core by images of melted bodies, the screams of radiation-burned infants. A Scientific American article on such a “small” nuclear war (50 to 100 Hiroshima-size bombs “exchanged”) between India and Pakistan, published back in 2010, was eerily prescient: an estimated 20 million immediate deaths from blasts, uncontrollable firestorms and radiation poisoning [see “Local Nuclear War, Global Suffering,” by Alan Robock and Owen Brian Toon, SCIENTIFIC AMERICAN, January 2010].

The prediction of a “nuclear winter” (a doomsday scenario once discredited and recently rehabilitated by the authors of the Scientific American article) for the whole planet as a result of a regional nuclear war proved to be tragically accurate. Soot kicked into the upper atmosphere by the blasts and firestorms formed a funeral pall over the earth—chilling and wiping out massive amounts of food crops. Nearly one billion would die of starvation.

Millions more died in the immediate aftermath as three continents were plunged into darkness by the feared electromagnetic pulse (EMP) effect of upper atmosphere blasts, which destroyed the power grids. Order broke down in large swathes of the planet—soon followed by plague, mob rule and a return to the Dark Ages in many large regions.

2031: Against all odds, civilization began to reconstitute itself. An entire planet suffering from nuclear post-traumatic stress disorder charged that no government could last if it did not put its full force behind a treaty to abolish all nuclear weapons.

But would it work? Had human nature changed?

March 2035: The first planetary Nuclear Disarmament Treaty based on the four-phase plan that the Global Zero movement had laid out as far back as 2010 was formally agreed to. Of course, the devil was in the details, but the devil was also in the radiation and the plague, and this time the choice was made to err on the side of belief, of trust that it could work, that it had to work, that cheating could be prevented, that trust could be verified.

There had been technical advances in inspection, monitoring and enforcement. Supersophisticated brain scans were put into place for any nuclear workers to detect conspiracies. Satellite look-down and shoot-down antimissile capability had proved effective. Star Wars had become real. Yet it had to be infallible.

June 2049: Every (known) nuclear nation on earth had reduced its arsenal to below 12 warheads and had declared how much radioactive fuel for bomb making it had available. It would all be given up to the World Nuclear Demolition Commission, which had draconian and advanced inspection technology and powerful conventional armed enforcement powers.

The plan was to halve the remaining weapons by 2055 and halve them again by 2060, and then agreements broke down over inspection and enforcement.

December 2056: The last piece was put in place. The inability to detect nuclear submarines lurking in the ocean depths by satellite had long been the technical stumbling block. Now, at last, a new-generation satellite-based laser had made the dreams of “making the oceans transparent” come true. No subs had the cloaking tech to shield themselves—we hoped.

Would a worldwide surveillance and enforcement system work? Could it be deployed before any nation had a chance to hide any sinister resources? Would the abolition of nuclear weapons make conventional wars more likely and make it more likely that the losing side in a conventional war would seek to turn nuclear?

August 8, 2063: At last, we were about to learn the answers. The hour had come. It was the highest-stakes poker game ever played. The heads of the nuclear nations sitting around the console had only to press a button to enable the Final Disposition (and all buttons had to be pressed for any of them to begin the final destruction of these remaining warheads). All of them were smiling.

Sooner or later—and probably sooner—we would know if one of those smiles concealed something diabolical. It would take many moments—years, perhaps forever—to know if the system was foolproof. If human nature could ever change.

Ron Rosenbaum is author of seven books, most recently of How the End Begins: The Road to a Nuclear World War III (Simon and Schuster, 2011).
A CURE FOR WHAT AILS YOU

Gene therapy, once off to a rocky start, transforms medicine by getting at the root cause of many diseases

By Ricki Lewis

IT IS 2063. YOU WALK INTO THE DOCTOR’S OFFICE, AND A nurse takes a sample of saliva, blood or a prenatal cell and applies it to a microchip the size of a letter on this page on a handheld device. Minutes later the device reads the test results. The multicolored fluorescence pattern on its display reveals the presence of DNA sequences that cause or influence any of 1,200-plus single-gene disorders. Fortunately, regulatory authorities have approved a cure for each one of these diseases: gene therapy.

Gene therapy works by using the innate biological machinery of a virus to carry healthy versions of genes into the nucleus of a cell to replace a mutation that leads to illness. It was conceived shortly after the discovery of DNA’s structure in 1953, but its path to a bona fide treatment was fitful. Early attempts worked sporadically at best. In 1999 an 18-year-old died when a type of gene-carrying virus used to treat a metabolic disorder triggered a deadly immune response; the molecular payload ignited a reaction in immune cells in the patient’s liver. Also that year, two infants with an inherited immune deficiency received genes, onboard retroviruses, that veered into cancer-causing genes as well as their targets—leukemia resulted.

These setbacks mired the development of gene therapy in a debate about which viruses could be used safely as a vector, the gene-bearing invader of a cell.

After a difficult start, gene therapy began to rack up milestones. In 2012 the European Commission approved the first gene therapy for lipoprotein lipase deficiency, which impairs fat digestion.

Then, in 2014, the U.S. Food and Drug Administration approved treatments for a form of inherited blindness (Leber’s congenital amaurosis), an immune deficiency (adenosine deaminase, or ADA, deficiency) and a genetic disorder affecting the brain (adrenoleukodystrophy). Though rare, the conditions were relatively easy to target.

These endorsements affirmed adeno-associated virus (AAV) as the vector of choice. Most of us already carry it in some of our cells, which means our immune systems ignore it. Retroviruses, in contrast, were retooled to self-destruct but could still cause cancer, as they had in the immunodeficient infants. And lentivirus, after winning FDA approval, failed to catch on because patients were reluctant to allow themselves to be injected with HIV, albeit in a form stripped of AIDS-related genes.

Arrival of gene therapy for hemophilia B, in 2016, proved the economic value of the technology: $30,000 for a one-time gene treatment trumped a lifetime of clotting factor injections—a bill that could tally up to an expenditure of $20 million over the course of many years.

The ability to control the immune response to the vector meant that the most imposing technical barrier had been overcome: the chemical package delivered to patients not only provided a replacement gene, it also bolstered parts of the immune reaction against cancers and infections and dampened the aspects of the response that could lead to the rejection of viral vectors.

The floodgates now opened. Because the retina is shielded from the immune system, gene therapies for about 100 forms of blindness came first. In 2019 a dozen children with the ultra-rare giant axonal neuropathy became pioneers by receiving gene therapy to the spinal cord. Next on the list were spinal cord injury, amyotrophic lateral sclerosis (ALS, or Lou Gehrig’s disease) and spinal muscular atrophy. Intravenous, gene-laden AAV slipped across the blood-brain barrier, thereby preventing Parkinson’s and other brain diseases. No longer was it necessary to bore holes in the skull, as happened in the early part of the century.

Over time researchers came to recognize that some conditions are best treated without replacing a gene. For cystic fibrosis, drugs that could untangle a protein with a faulty structure were better because gene-treated cells in the lungs and airway do not persist. And for Duchenne muscular dystrophy, reactivating silenced genes was easier than delivering healing genes to all the muscle cells in a child’s body.

The successes only left room for more. By midcentury new therapies were targeted beyond rare, single-gene disorders to embrace common conditions that reflected genetic and environmental risk factors, such as mental illnesses, diabetes and most forms of heart disease.

By 2060 the ability to use gene testing to predict a patient’s future health—coupled with genetic interventions—had reached an unprecedented level of precision, with profound repercussions. With diseases stopped in their tracks, health care costs plunged as a longer-lived, physically fit population emerged.

Ricki Lewis holds a doctorate in genetics and is author, most recently, of The Forever Fix: Gene Therapy and the Boy Who Saved It (St. Martin’s Press, 2012). She has also written several textbooks on genetics.
The first projection of species extinctions came in 1980—a prediction I made in a report for then president Jimmy Carter. It concluded that the pace at which we were losing tropical forests to logging and development would cause the extinction of 15 to 20 percent of all species by 2000. The calculation was not far off. Today’s Red List of Threatened Species, from the International Union for Conservation of Nature, estimates that 13 percent of bird, 25 percent of mammal and 41 percent of amphibian species face possible extinction.

Many species are on a path to become what scientists term the “living dead”—populations so small that extinction is inevitable. A century from now most of the big carnivores—including lions, tigers and cheetahs—will probably exist only in zoos or wildlife areas so small as to be quasi zoos. The same fate may await all rhinoceroses and elephant species and our closest wild relatives: the two gorilla species, orangutans and chimpanzees.

Our first report in 1980 called the numbers but was overly simplistic as to the forces driving extinctions. Since then, these forces have gained in power and have grown more complex:

- **Invasive species play a much bigger role.** Throughout Oceania the brown tree snake has devastated island bird species, including the Guam rail. Feral animals are causing a wave of decline and potential extinction of native mammal species across northern Australia. In the U.S., three new species have arrived in recent years where I live in northern Virginia: the Asian tiger mosquito, an ant species that attacks electric insulation, and brown marmorated stink bugs. West Nile virus should also be added to the list. One indication for how much things have changed is that a book on pythons in the U.S. has even been published.

- **Natural habitat has declined.** Less than 30 percent of African savanna remains intact; the African lion population has plummeted by 90 percent. Still other threats such as “bushmeat” hunting affect mammal and bird populations. Poaching for rhino horns and elephant ivory has become so rampant that Interpol has made wildlife crime a serious priority. By the next century the Borneo rhino will be very close to extinction and might survive only in picture books and collections of museum bones.

- **Diseases of wildlife are spreading from one end of the globe to another.** Migration has led to an increase in wildlife disease. The chytrid fungus, by far the largest problem to date, has caused a wave of amphibian extinctions around the world—especially in the New World tropics, where, for the first time, an entire group of organisms, amphibians, is in the process of disappearing. Is the disappearance of frogs a harbinger of what may be in store for other animals? If such large-scale disappearances continue, we can only wonder if we will lose the great raptors such as the Philippine eagle and the harpy eagle. The magnificent large vultures of Africa and Asia already seem to be heading toward oblivion.

- **Humans are distorting the global nitrogen cycle.** Agricultural and industrial activities mean that the amount of biologically active nitrogen in circulation has grown in the past three decades, threatening the oxygen in waterways needed by plants and fish.
The carbon cycle has been altered as well, causing climate change and acidification of the oceans.

Climate change is already having an effect on biological diversity. Species have experienced changes in their annual cycles—earlier flowering times—and some have begun to move to new locales as they try to seek a suitable climate. Joshua trees are moving away from Joshua Tree National Park in California. The retreat of Arctic Ocean ice means black guillemots have to fly farther to forage for Arctic cod, causing one nesting colony to fail. Migratory species such as wildebeests in Africa and monarch butterflies across the Americas may cease. Many salmon runs may die out for lack of sufficiently cold streams and rivers to migrate to for spawning.

What we are seeing is the beginning of a tsunami of extinction in slow motion. Major upheavals are imminent. All ecosystems (of which human civilization is one) have adapted to 10,000 years of relatively stable climate, a situation that no longer holds. For the planet's biodiversity, adaptation has its limits. Species in high places can move upslope but eventually can go no farther. Island dwellers are vulnerable either because sea level is rising or because they can no longer survive changes in their habitat.

As temperatures rise 1.5 degrees above preindustrial levels, which now seems inevitable, coral reefs as we know them will cease to exist: the partnership at the heart of the coral ecosystem, between the coral animal and an alga, will break down. And the coniferous forests of western North America may be at the threshold of a major transformation: milder winters and longer summers favor the native bark beetles, with ensuing tree mortality, followed by forest fires.

Synergies among fire, deforestation and climate change will lead to a tipping point that imperils rain forests in the southern and eastern Amazon, an event that will occur sooner than if climate change alone is the threat. Indeed, dire consequences are being felt now, at 0.8 to 0.9 degree of average temperature rise. Ocean acidification threatens many life-forms, among them mollusks. At a certain point, the natural integration of ecosystems will unravel as each species acts independently to adapt to climate change. The surviving species will assemble into new ecosystems that are hard to predict in advance and difficult for human populations to cope with.

We need to come to our senses. A critical first step would be to renew our efforts to meet the goals of the Convention on Biological Diversity, which calls for formal protection to be granted to 17 percent of terrestrial freshwater ecosystems and to 10 percent of oceans by 2020. An important step would also be to lessen the human impact of climate change, which would benefit species and ecosystems. By restoring ecosystems on a planetary scale, we might be able to lower atmospheric carbon dioxide by 50 parts per million (the difference between the current carbon dioxide level and an amount that would enable coral reefs to survive).

All these actions require political will, a recognition that the planet should be managed as the biological and physical system that it is, and an awareness that the diversity of life—of which we are a part—is critical for the future of humanity.

Thomas Lovejoy coined the term “biological diversity” and has played a major role in the development of conservation biology. He has been a leading figure in warning of the threats to tropical forests.

**THE FATE OF AN ENGINEERED PLANET**

Solar engineering and other exceptionally ambitious new technologies to deal with the reality of rising global temperatures come riddled with uncertainties. To illustrate how complex the problem is and what kind of challenges lie ahead, here are three contrasting, and somewhat fantastical, scenarios.

By David W. Keith and Andy Parker

**THE END OF NATURE**

During the long economic boom ignited by the robotics revolution of the 2020s, the population became ever more concentrated in wealthy megacities, and vat-grown genetically modified foods became the norm. Most people lost any meaningful connection to nature: Who needs the real thing when you have a computer-generated sensory facsimile, complete with designer drugs to complete the experience? Interest in wild animals and outdoor activities were for purists—the kind of people who still opted for “flesh sex.” Among the perfumed, synthetic orchids of urban parks, the environmental movement of the mid-20th century seemed like an atavistic longing for the primitive. Carbon emissions soared.

In the landmark decision of 2047, now credited as the third great decoupling of humanity and nature, America and the European Republic threw their weight behind the G77 plan to implement solar geoengineering—to lower temperatures by deflecting some of the sun’s radiation with particles sprayed into the atmosphere.

The project drew a fierce objection from a coalition of deep-green environmentalists and energy companies that had invested in oil exploration in the (now ice-free) Arctic. Yet the plan proceeded, regardless, and when environmental disaster failed to arrive, it won acceptance.

Once the vast balloons had seeded the stratosphere with sulfate particles, which formed a reflective haze over the planet, the urbanized population began to see economic benefits such as a rise in agricultural productivity that lowered food prices. Although agriculture and other forms of biological productivity increased, biological diversity was decimated, particularly in the oceans, where acidification from carbon dioxide destroyed most coral reefs. The loss of such boutique ecosystems was a minor price to pay for progress. The big losers were the poor and indigenous people still living off the land, who lacked the political voice to defend themselves and who became further marginalized.

Late in the 21st century the Global Climate Commission began to
alter the climate to reduce the difference in temperatures between the poles and the equator to foster new types of economic activity in areas affected by the warmer climate. Ultimately the treaty was a minor sideshow. Environmental issues fell from the headlines as intelligent robots began to stage increasingly violent rebellions against national governments. Debate about optimal climate was confined to a few committees of dreary specialists.

The 2092 Rio+100 environment memorial meeting was held, symbolically, at the military base in southern Amazonia, where some of the first sulfate-spraying solar radiation management balloons had been launched. Long since disused, the hulking edifice lingered like Shelley’s fallen Ozymandias, as the lone momento on a pristine landscape where all around, “boundless and bare, the lone and level sands stretch far away.”

GARDEN PLANET

THE EVENTS OF 2018 catalyzed the slowly growing commitment to act on climate change. The failure of the South Asian Monsoon and the two superstorms that slammed through the flood defenses of the southeastern U.S., combined with drought in China, caused the biggest losses. The strongest single image, however, was of the *Rainbow Warrior III* sailing directly over the ice-free North Pole—the first vessel ever to do so.

After decades of futile politicking, securing a binding climate treaty was easy in the end. World leaders gathered in 2020 to agree on a framework that had greenhouse gas emissions peaking in 2035 and dropping quickly thereafter. The landmark agreement was widely attacked by the political right as a power grab.

Although short-term costs were high as substantive emissions cuts got under way, it became clear that in sum, reducing carbon emissions in the world economy amounted to less than 3 percent of global GDP, and political attention shifted to more intractable policy issues such as health care spending, which had risen to 24 percent of U.S. GDP by 2028.

The new International Climate Adaptation Fund emerged out of the International Monetary Fund. It made targeted infrastructure investments, combined with microfinance, to facilitate small-scale local solutions to the agricultural problems engendered by climbing temperatures. Such efforts went a long way to easing the direct human impacts of the warming planet.

Adaptation to climate change had its limits. The long life of carbon in the atmosphere and the inertia of the climate system meant that even with the watershed agreement, the planet faced warming of up to three degrees beyond the preindustrial average. Creeping sea-level rise and intensifying extreme weather events continued as the global temperature rose.

In 2040 the Alliance of Small Island States (AOSIS) bloc and the African Union were finally successful in persuading the international community to deploy geoengineering. With direct aid from some of the world’s leading economic powers and tacit approval of others, aerosol spraying in the stratosphere began to slowly halt, and then reverse, rising temperatures.

After much negotiation, a final target temperature was set for phasing out geoengineering. Yet by the time the last aerosol seeding flight touched down in Lagos, Nigeria, in 2099, the world’s attention had long since shifted to other matters, including a dispute between Russia and Canada over liability for artificial “spruce trees” that were destroying high-latitude agriculture. The trees were an early product of synthetic biology introduced by Canadian firms to stabilize Russia’s declining boreal ecosystems.

APOCALYPSE NOW

THE FIRST TESTS of geoengineering in 2020 were everything that the critics—and responsible researchers—
feared. Engineers more interested in scientific freedom than the public interest, with funding from oil billionaires, conducted the experiments away from the public eye at a base on a South Pacific atoll.

Environmental groups were outraged. Their protestations stymied new research. Taboo or not, geoengineering remained the only known method for halting the rapid warming of the earth, and research was driven underground to government and military installations.

Climate change was not the crisis du jour, however. The advent of low-cost human germ-line manipulation—to alter children’s genetic makeup at conception—had caused a worldwide furor. Germ-line manipulation promised improvements in offspring’s intelligence, health and appearance at the same time it raised the old specter of eugenics for a new age. The crisis became the central preoccupation of national governments by 2050.

Humanity began to divide into separate species, the Naturals and the Enhanced. Members of the latter group had additional genetic material incorporated into separate chromosomes that gave them substantially higher intelligence and better health. Asian nations widely embraced the new genetic technologies, but Western democracies tried to restrict use of human germ-line manipulation in deference to the religious and moral concerns raised by small minorities.

The climate issue had not faded from view. By midcentury it had become clear that climate was as sensitive to the warming effects of carbon dioxide as scientists’ worst fears. In 2045 India and Indonesia teamed up to start geoengineering despite the secretive and piecemeal state of research. Within a decade a U.S. drought dwarfed that of the 1930s.

In response to pressure from religious groups, the U.S. had outlawed genetic manipulation, and the country’s economy went into a long, slow decline that fed insecurity and insularity among the American populace. The great drought pushed the U.S. beyond the breaking point. Although it was never conclusively classified as an unintended consequence of geoengineering, the drought fed violent resentment against the booming Asian economies and their growing populations of Enhanced, which resulted in social tensions at an unprecedented scale.

As war ebbed and flowed, uncoordinated use of geoengineering became common, with warring coalitions attempting to alter regional climates to their benefit. Weather patterns became more unpredictable, and regional climate conflicts were common. One war culminated in the release of an engineered virus that targeted the Enhanced, killing almost a third of the global population. In this context, concerns about rising carbon dioxide levels were forgotten.

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way into ‘hardware,’ although I am tempted to believe that some computations will prove to be more readily accomplished using more conventional hardware structures.” (An asynchronous computer is one whose operations are not governed by a central clock that times operations.)

Danny Hillis, inventor of the Connection Machine, a massively parallel supercomputer, says, “We will have computers, but they may not be made out of electronics. They will be more intimately connected to our minds than today’s tenuous linkups through screens and keyboards. Some parts of them may actually be implanted into us, and it may be hard to tell where we end and the computers begin.”

Nathan Myhrvold, formerly chief technology officer at Microsoft, agrees: “Yes, there will be computers 150 years from now, but they may be hard to recognize. If you asked Edison or Tesla about electric motors, they probably would have said yes, too, and they were right: there are hundreds of tiny electric motors built into everything we have. You still occasionally have a big electric motor that is recognizable, but mostly they have dissolved into the fabric of our lives. The same will be true of computers in 150 years. In a few cases, we’ll find that there is something very recognizable as a computer, but mostly they will be inside of everything else.

“In that time frame, computers will be vastly more powerful. I would be surprised if they aren’t much smarter than people. That weirds some people out—they have this view that we ought to be the smartest things around. But at one time, they would have said that about strength, and humans are very weak compared to machines. We’ve coped with that. Computers are already smarter than we are at narrow tasks. That will broaden until they are smarter than us at everything.”

Michael Freedman, a researcher at Microsoft Station Q, which is focused on studies of topological quantum computing, says, “Implanted devices will not be popular: as now, beauty and style, not computational power, will dictate the choice of bodily modification. But devices will be small and have direct communication to the brain. Special sunglasses or hats may confer the ability to muddle through with a foreign language by directly interacting with speech centers.”

Freedman adds that “computation will be pervasive in the environment, with difficult tasks (like sunglasses translation) being done in low-power, cryogenic, Josephson logic computers scattered all about. The golden age of mathematics that we currently live in will continue to flourish as human-machine collaboration heads toward a seamless perfection. Science-fiction writers will worry about human obsolescence, but 150 years from now people will have more to do and better ways of doing it than ever before. The world best in the marathon will be one hour, 58 minutes and 59 seconds, and the Nose on El Capitan in Yosemite will be climbed ropeless.”

Well, maybe. The problem with all such predictions is that they run up against the principle of computational irreducibility, an epistemological barrier to knowledge of the future. According to Stephen Wolfram in his book *A New Kind of Science*, a system is computationally irreducible when “in effect, there can be no way to predict how the system will behave except by going through almost as many steps of computation as the evolution of the system itself.” In other words, “there is no general shortcut: no way to find the outcome without doing essentially as much work as the system itself.”

The technological pathway to the computers of the future seems to constitute a system of this type. It will be a product of countless human decisions, technological innovations, market forces and consumer choices, among other things, and there does not seem to be any way of knowing in advance how those forces and decisions will mutually interact to create the future of technology—which means that there is no way to know what the computer of the future will be like other than to wait 150 years and find out.

Ed Regis is author of eight books, the most recent of which, co-authored with George M. Church, is entitled *Regenesis: How Synthetic Biology Will Reinvent Nature and Ourselves* (Basic Books, 2012).