The Beginning: 2026-2046

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Introduction: Living at 2 °C

It is 2046.

This year, scientists announced that the world's average temperature is now 2 °C hotter than it was in the late 19th century, when humanity's greenhouse gas emissions were just beginning to alter the climate.

It feels like it shouldn't matter. I'm not sure I'd notice if my room warmed by 2 °C. But when averaged out over the whole Earth, it represents an almost unimaginable accumulation of heat. Worse, that heat isn't spread out evenly. Land has warmed about twice as quickly as water. The Arctic has warmed four times faster than the world as a whole.

And it's not like every day is just a bit warmer. The worst heat comes in waves, and the waves are much hotter than anything people have felt before. Heatwaves that were once-in-50-year events in the late 19th century now happen every few years. And heatwaves that were simply too hot to happen are now all too real – and all too deadly.

Changing temperatures are disrupting precipitation patterns. Rains don't come as expected, or they fall too hard, too fast. Water in soil dries up so quickly that ecosystems are beginning to break down. Now, the world's food growing regions, its *breadbaskets*, no longer produce enough food for the world's 9.4 billion people.

I was born in 2026, when average global temperatures were about 1.4°C warmer than they had been in the late 19th century. In my lifetime, a threat that once must have felt distant and abstract – *climate change* – became a matter of life and death for hundreds of millions of people.

This is the story of how we got here.

2026-2046: Emissions Plateau, But Warming Continues

When I was born, most governments still supported the goals of the 2015 Paris Agreement. In public, they pledged to limit warming to “well below” 2 °C, relative to Earth’s average temperature in the late 19th century.

In private, policymakers understood that they had little chance of meeting that goal. Human emissions of carbon dioxide, the greenhouse gas most responsible for global warming, were plateauing – not falling. That distinction, between stabilization and decline, turned out to matter enormously.

By the late 2020s, global carbon dioxide emissions peaked at roughly 40 billion tons per year. Many celebrated that emissions had stopped rising. Politicians took credit. Pundits argued that global warming wasn’t, after all, the crisis it had seemed to be. Leading scholars declared that by tackling the emissions problem, governments had shown the capacity to deal with other, world-threatening issues – like the continued development of artificial intelligence (AI).

But carbon dioxide takes a long time to leave the atmosphere. True, it was no longer accumulating as quickly in the atmosphere as it had been. But overall atmospheric concentrations of the gas were *still* rising, trapping heat from the Sun by absorbing and re-emitting infrared radiation that would otherwise have escaped into space.

And because emissions didn’t fall, global temperatures continued to rise. By 2036, when I was ten years old, the world had warmed by about 1.7°C since the late 19th century.

The impacts were growing more severe. Heatwaves, for example, were ever more frequent and long-lasting, especially in already hot regions, like South Asia and the Middle East. Cities such as Mumbai and Riyadh began experiencing life-threatening heat for ten days at a time, several times a year.

Thousands of people died in these heatwaves. But the death toll tended to be even higher in regions where there had been no historic need for cooling: much of Europe, for example. Heatwaves with no precedent in recorded history were now routinely associated with tens of thousands of deaths.

At the same time, droughts intensified.

Part of the reason was that a warmer atmosphere could hold more moisture: about 7% more for every degree Celsius of warming. So when it rained, it often rained more intensely. But when it *didn’t* rain, the atmosphere could pull more water out of soils and vegetation, drying them faster. A warmer world paradoxically led both to wetter storms *and* deeper droughts.

Both torrential rains and severe drought ruined harvests in one food-growing region after another. But during my childhood, the worst extremes rarely affected multiple regions at once.

For most people, in most countries, their impacts still seemed manageable. One country might suffer drought, but others would produce enough food to compensate. Global trade tended to ease local spikes in food prices.

New technology – from increasingly reliable, AI-generated weather forecasts to genetically modified organisms (GMOs) – kept yields high. The world's food system seemed too flexible, too interconnected, and above all too modern to fail.

That would soon change.

2036-2042: Cracks in the System

As global temperatures began to approach 2 °C above their late 19th-century average, what changed wasn't just the intensity of heatwaves and droughts from one region to the next. It was also their synchronization in regions all over the globe.

Climate scientists had long warned about this possibility. As the Arctic warmed far faster than lower latitudes, the temperature contrast that fueled the polar jet stream weakened. The jet stream began to slow and buckle into larger, more exaggerated loops: patterns known as Rossby waves.

At times, these waves stalled in place. Now, areas separated by thousands of kilometers could experience similarly extreme weather at the same time: simultaneous heatwaves, droughts, or torrential rains.

This mattered most for agriculture. The world's food supply depends heavily on a handful of key regions, known as *breadbaskets*. These include the U.S. Great Plains (where corn and soybeans are the key crops); Brazil and Argentina (soybeans, maize, and beef); Northern China (wheat and maize); India's Punjab and Haryana (wheat and rice); and parts of Europe and the Black Sea region (wheat).

Harvests in these regions had rarely failed at the same time. But in the late 2030s, that began to change. Prolonged heatwaves reduced yields in southern Europe and parts of China. Droughts intensified in Brazil, where soybean production depends on consistent seasonal rainfall.

Meanwhile, groundwater depletion accelerated. In places like northern India and the Great Plains, farmers had been able to pump water from underground aquifers when rainfall failed. But these aquifers, some of which had filled over thousands of years, were being drained more quickly than they could refill.

And as temperatures rose, and evaporation increased, crops needed more and more water just to survive. Irrigation demands surged, accelerating the depletion of groundwater. A dangerous feedback loop had emerged, in which higher temperatures led to more evaporation, more evaporation led to more demand for water, more demand led to more groundwater depletion, and less groundwater increased vulnerability to drought.

The ocean was also becoming a less reliable source of food, because the coral reefs were under increasing strain.

Granted, the oceans were warming less quickly than land. But in shallow water, marine heatwaves brought unprecedented temperatures – just as they did on land. Under heat stress, corals expel the algae that usually provide most of their food, causing them to turn white, or "bleach." If the heat lasts too long, the corals begin to starve.

Ocean water was moreover absorbing carbon dioxide from the atmosphere. The gas reacted with the seawater to form carbonic acid, lowering the pH of the water – and the availability of the ions corals need to build their skeletons. It was growing harder and harder for them to recover from bleaching.

In the late 2030s, most of the world's reef systems were clearly dying out. Roughly one-tenth of the global fish catch depended on coral reef ecosystems. Across the tropics – parts of Indonesia, for example, and coastal Madagascar, where millions already struggled with deadly heatwaves – reef fisheries actually provided the majority of people's protein.

When I entered high school in the early 2040s, I learned to my alarm that the world's food system was under increasing strain. My teachers assured me, however, that experts were working on the problem. They said that there would still be enough food for the foreseeable future.

And I discovered that about a third of the food grown in the United States is never eaten. For a few years, that calmed me down.

But only for a few years.

2042-2044: Decarbonization, Rising Emissions, and a New Baseline

The green economy expanded enormously in my lifetime.

For a while, it looked like American and European governments and companies would lead its expansion. But even before I was born, the U.S. government slashed its goals for decarbonization and pulled out of the Paris Agreement, the 2015 treaty that aimed to limit global warming to well below 2°C. After the Russian invasion of Ukraine, the transition to renewables stalled even in Europe – at least for a few years.

China would lead the transformation of the world's energy system. The country's central and provincial governments, together with state-backed banks, used subsidies and cheap credit to direct vast investments, amounting to trillions of dollars, into solar, wind, and electric vehicles.

These dividends paid off when the U.S/Iran war of 2026 revealed the precarity of globe-straddling trade networks that transported fossil fuels.

By 2040, the world's economic center had moved decisively to China, and some 50% of global electricity came from renewables. In many regions – cities across coastal China, for example – deaths from airborne pollutants fell sharply.

But although the world's energy system was changing with a speed few had imagined possible, global warming was barely slowing down.

The problem was that worldwide demand for electricity had also surged. Part of the reason was the breakneck construction of new data centers to power increasingly capable AI systems. Another part was continued economic development in South Asia, Africa, and South America, and continued high consumption in the developed world.

So, while fossil fuels accounted for a smaller *share* of global energy use, the *total* amount of energy generated by fossil fuels had scarcely declined. Meanwhile, greenhouse gas emissions from industry and agriculture remained stubbornly high.

By the early 2040s, AI systems with seemingly superhuman intelligence occupied increasingly important advisory roles within governments and corporations. The construction of the physical infrastructure that powered these systems had released carbon dioxide into the atmosphere, and the operation of the systems generated even more emissions where the grid depended on fossil fuels.

It was therefore ironic that AI advisors, which had contributed to global warming, provided the warnings that finally transformed how many governments perceived the risks of climate change.

But it increasingly seemed like it might be too late. Baseline conditions in many breadbasket regions had shifted. Catastrophic heatwaves, droughts, and floods were no longer anomalies. Now, they were expected during the growing season.

Crops like wheat and maize are highly sensitive to temperature, especially during key growth stages. When temperatures rise too high, even briefly, harvest yields can drop sharply. Prolonged heat compounds the damage.

Worse, soil moisture had declined in most regions. Dry soils don't just affect crops; they also amplify heat. Moist soils use incoming solar energy to evaporate water, which has a cooling effect. Dry soils can't do that, so more energy goes into raising temperatures.

This created another feedback loop: drought dried soils, dry soils increased heat, and increased heat worsened drought.

By 2044, this cycle had firmly established itself in multiple regions. Harvests were growing dangerously unreliable. In parts of the developing world, especially East Africa and West Asia, food prices were rising beyond the reach of poor families. Popular discontent mounted, and violent protests began to threaten governments.

The worst was yet to come.

2044–2045: The Failure of the Breadbaskets

In early 2044, AI systems forecast the development of a landmark El Niño event – the most intense since 2027.

El Niño refers to a periodic warming of surface waters across the tropical Pacific Ocean. This warming disrupts global atmospheric circulation, altering rainfall patterns around the world.

The 2044 El Niño developed between March and May, and by late summer turned out to be as powerful as predicted. It intensified drought in several key agricultural regions simultaneously. India's summer monsoon weakened dramatically; Southeast Asia experienced below-average rainfall; parts of Brazil became even drier; Southern Africa faced severe drought.

Extreme heatwaves in ocean water, known as *marine heatwaves*, bleached nearly all of the world's coral reefs.

For India, the consequences were especially severe. In just a few months, beginning in June, the summer monsoon usually provides up to 80% of India's annual rainfall. Across eastern and southern India, monsoon rains inundate paddies where farmers grow vast quantities of rice.

But in 2044, the rains didn't come, and the rice didn't grow.

Irrigation systems began to fail. In India's Punjab and Haryana, decades of groundwater extraction had already lowered water tables. Pumps had to reach deeper to extract water, requiring more energy. Now, some wells simply ran dry. There wasn't enough water to grow wheat, much less rice, which requires more moisture.

In the Great Plains, parts of the Ogallala Aquifer, the region's main groundwater source, were severely depleted. Farmers who had once relied on irrigation depended on rainfall that no longer came reliably. Without irrigation as a backup, many plants withered and died.

Last year, in 2045, the worst-case scenario, the one scientists had warned about for decades, finally materialized.

Multiple breadbasket regions experienced severe yield losses in the same year. The U.S. Corn Belt saw staggering declines due to heat and drought. Brazil's soybean harvest fell sharply after prolonged dry conditions and wildfires. Harvests in India and Pakistan failed amid consecutive weak monsoons. Northern China endured extended heatwaves during key growing periods.

It was a global crisis unlike any in modern history. Normally, shortages in one region had been offset by surpluses elsewhere. But in 2045, there were no surpluses.

There was simply not enough food to go around.

2045–2046: The Great Hunger

As harvests collapsed, governments struggled to protect their populations. Major exporters restricted food exports. This was a rational decision at the national level, but devastating globally.

Countries that depended on food imports suddenly faced severe shortages, especially in parts of the Middle East, North Africa, and sub-Saharan Africa. Global food prices soared. Markets that had once redistributed food efficiently began to break down.

By late 2045, food prices had tripled in many regions.

The wealthy worried about unrest. The middle class suffered financial hardship. And the poor went hungry.

Malnutrition increased rapidly. In the hardest-hit regions, such as North Africa and the Middle East, food shortages combined with extreme heat, water scarcity, and suffocating wildfire smoke.

Public health systems, already strained, began to fail. Migrants poured into cities from the stricken countryside, but most found little food and no work. Other migrants surged across national borders, and at first there was little governments could do to stop them.

Political instability followed. Massive protests – echoing the "Arab Spring" of the early 2010s – threatened governments in one overcrowded city after another. Refugees were demonized as invaders, and governments were blamed for their arrival.

Many regimes responded with brutal repression. Migrants were shot at the border and detained in sprawling camps. Protests were broken up and banned.

But repression only fueled more anger. After all, governments could not provide food. And for all their promises they had failed to slow down global warming.

As I write this, six governments have collapsed across Africa and the Middle East. Elsewhere, political violence runs rampant. Government buildings have been sacked. Politicians have fled capitals.

Millions have died in the violence.

And the true scope of this year's global disaster is only just coming into focus. The death toll is hard to calculate in the hardest-hit areas, where data are difficult to obtain. But AI systems estimate that tens of millions have died not just in revolutions, but from the combined effects of famine, disease, and heat.

The vast majority of these deaths seem to be concentrated in the poorest parts of the Middle East and Africa. But many have also died in historically marginalized communities within the richest cities of North America, Europe, and Asia.

The Great Hunger, as some now call it, could be the worst mass mortality event since the Second World War.

Environmentalists call it "The Great Betrayal." After all, it was predicted, and it could have been avoided. Many blame billionaires, oil companies, and politicians in the world's richest countries for the death toll.

Terrorist attacks are beginning to hit pipelines, refineries – even wealthy neighborhoods in the world's biggest cities. Although it's only worsening inflation, this eco-terrorism seems increasingly popular.

In a warming world, nobody can truly feel safe.

2046: An Uncertain Future

What is most striking, looking back from 2046, is not that any single event was unprecedented. Droughts had happened before. Heatwaves had happened before. Strong El Niño events had happened before.

What changed was their overlap. Warming didn't just make individual events more severe; it made them more likely to occur at the same time, in the same critical regions.

Synchronization is what broke the world's food system.

Even now, with the world 2 °C hotter than it was in the late 19th century, scientists and AI advisors argue that there's still time to avoid a permanent, worldwide breakdown of the systems that sustain human life.

There's clearly a need for more climate-controlled agriculture. And AI systems are already designing crops that could thrive amid droughts and heatwaves.

Still, it’s obvious that there are hard limits to what adaptation can achieve without mitigation. Global temperatures have to stabilize. Otherwise, there will be many more multiple breadbasket failures in our future.

Time is scarce. The coming decades are deeply uncertain, and frightening for many in my generation.

I was born into a world that still had options. Our parents chose not to use them, and now we must all face the consequences of their inaction.

We can only hope that it’s not too late to save our societies, our species, our planet, and our future.

Survival Through Geoengineering, 2046-2100

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Introduction: A World That Endured

It is 2100.

The long battle to slow, stop, and finally roll back global warming may be nearing its end.

It's easy to assume that the battle was won. The world's human population stands at about 10 billion. Modern societies are much wealthier and healthier than those of the early 21st century.

And technology is changing what it means to *be* human. Most people have cybernetic implants and enhancements. It's no longer easy to distinguish between biological and synthetic humans.

I imagine that today's world must have seemed like an impossible dream in 2046, when my parents were born in Charleston. Then, an estimated 60 million people had just died in the Great Hunger. The world had warmed by 2 °C, relative to its average temperature in the late 19th century. Ecosystems were collapsing, led by coral reefs.

It's hard to piece together how people felt, so many decades ago. But it must have looked like there would never again be enough food to go around. Like the Earth was destined to heat up until there was no place left for billions of people.

I imagine that humanity looked like it was doomed. But 2046 was not the beginning of the end of the human story.

In the decades that followed, societies didn't exactly *solve* the climate crisis. Instead, governments and institutions worked to *contain* it. Through a combination of emergency geoengineering, uneven adaptation, and partial decarbonization, global temperatures stopped rising, then started to decline.

Much was lost.

Charleston was evacuated. Thousands of its most vulnerable people died, and many of its buildings were ruined. But its population returned, and rebuilt. Today, the city is growing again.

Global civilization has survived, even thrived. And Earth remains habitable – in most places.

2046-2056: The Geneva Climate Compact

By 2046, electricity generated by renewables had been surging for about three decades. It wasn't enough.

Part of the problem was that although fossil fuels supplied a smaller *proportion* of the world's total energy, they still provided just as much energy, overall, as they had two decades earlier. Another part was that emissions from land – rather than industry or transportation – continued to rise.

Population growth and economic development fueled a steady increase in demand for food, especially high-protein dairy and meat. In the tropics, ranchers burned rainforests to make way for fields and cattle farming. Livestock grazing consumed about a third of the world's land.

Because forests usually absorbed more carbon dioxide than they released while clearing and maintaining fields – especially for cattle – did not, food production was a growing contributor to global warming. By 2046, the electrical grid may have gotten cleaner, but cultivated land had not.

In the wake of the Great Hunger, many noticed the irony: the world's food system had succumbed to a disaster partly of its own making.

Regional heatwaves, droughts, and wildfires were not new in the 2040s, but arable land had always recovered quickly. Now, in the face of extreme weather on a truly global scale, and in the wake of decades of unsustainable groundwater depletion, vast stretches of farmland were abandoned across the world's breadbaskets.

According to my grandparents, even in small, wealthy cities like Charleston, South Carolina, grocery store shelves were often empty. Food banks were routinely overrun.

The United Nations Secretary-General convened an emergency session in late 2047, the first of its kind since the COVID-19 pandemic. During the Great Hunger, inflation had reached such highs, and the death toll seemed so extreme, that inaction was politically untenable – even for the most reluctant governments.

The European Union drafted a provisional framework for coordinated climate intervention, drawing on climate finance mechanisms that had been debated but underfunded for decades. The United States and China, both facing domestic political crises, signed on early. Governments that initially resisted the agreement, ostensibly to preserve national sovereignty, found that the famine had eroded their leverage.

Finally, in 2049, the Geneva Climate Compact came into force.

It operated on two tracks. The first brought in the countries that had lacked the technology or capital to transition away from fossil fuels – countries such as Vietnam, Thailand, Pakistan, Nigeria, Malaysia, and Indonesia. Wealthy signatories agreed to provide concessional loans, grants, and direct technology transfer to help poorer countries build out solar or wind capacity. For the receiving nations, the famine had removed any remaining hesitation. They signed because they had no other options.

The second track bound the world's largest economies to accelerated decarbonization timelines. China, India, and the United States were most important - for different reasons.

By 2049, about a third of the world's carbon dioxide emissions came from China. That was only a slight reduction from China's contribution to those emissions about 20 years earlier.

India was the world's fastest-growing economy, and electricity generated by renewables had surged across the country – but so had total power generation. India's carbon dioxide emissions were therefore rising quickly.

The United States, the world's largest oil and natural gas exporter for nearly 30 years, had periodically used its influence to thwart global efforts to roll back fossil fuel consumption.

Now, the three superpowers joined other signatories in committing to phase out coal; expand solar and wind power; and subsidize a shift toward regenerative agriculture. In practice, that meant measures such as cover cropping, no-till farming, and agroforestry: all intended to restore carbon to soils that had lost much of it through decades of intensive cultivation.

Not since the 2015 Paris Agreement had a diplomatic breakthrough created real hope for solving the crisis of climate change.

2056-2061: The Impacts of Climate Change Intensify

In the early 2050s, technology transfers were beginning to show results across Southeast Asia.

Vietnam and Indonesia rapidly scaled up solar capacity, reducing their dependence on coal. India's regenerative soil subsidies were rebuilding soil health in the parts of Punjab that were devastated by the 2044-45 El Niño.

But the atmosphere didn't respond to political timelines.

In many cities, dangerous heatwaves and suffocating wildfire smoke made life unbearable for weeks at a time. Devastating storms and floods were now routine disasters.

Vectors for disease, such as ticks and mosquitoes, had spread far beyond their 20th-century ranges. Epidemics happened far more frequently, as crumbling ecosystems led to more and more chance encounters between wild animals, with their unfamiliar bacteria or viruses, and people.

Poring through reams of mortality data, AI analysts warned that global warming was, indirectly, becoming a major cause of death. But even in that grim context, two disasters stood out.

In August 2056, Super Typhoon Vera made landfall in the northern Philippines with sustained wind speeds exceeding 330 kilometers per hour – stronger than anything the archipelago had endured in recorded history.

Computer simulations of Earth's climate – known as climate models – had long indicated that while the total number of tropical cyclones might decrease in a warming world, the proportion reaching super typhoon intensity would increase dramatically, as warmer ocean surfaces pumped more energy into increasingly devastating storms.

Vera revealed just how deadly the new "category 6" cyclones could be. Storm surges swallowed coastal rice paddies that had only just begun to recover from the Great Hunger. Owing in part to sea level increases, many were permanently inundated.

Hundreds of thousands were displaced into a relief system already strained by years of food insecurity. Some 28,000 people died – immediately, during the floods, and later, owing to shortages of food and medicine. It was the worst natural disaster in the history of the Philippines.

Then, in the summer of 2061, Hurricane Celeste, another category 6 storm, made landfall near Charleston with sustained wind speeds that rivaled Vera's. The hurricane had approached the coast as a category 1, and many hadn't heeded evacuation orders. But just before landfall, it intensified with unprecedented speed. Thousands of people suddenly faced the worst hurricane in American history.

Flooding caused by storm surges, combined with extreme winds, killed over 13,000 people, and displaced hundreds of thousands more along the eastern seaboard. Tens of thousands of structures were destroyed or damaged beyond repair, including most buildings in Charleston's historic city center. Estimated damages exceeded $2 trillion (in 2061 USD) for the first time in American history. But the worst losses couldn't be quantified.

My parents lived in Charleston, and were teenagers at the time. They were among the few to evacuate. But their family – my family – never really recovered. My parents lost two cousins, nine and twelve years old, and their aunt. They lost their childhood home, their school, and some of their best friends.

Worse still, climate disasters increasingly compounded each other. When Celeste passed, for example, a heatwave pushed temperatures across South Carolina beyond 38 °C – about 100 °F – for over a week. Because millions were without air conditioning and the health system no longer functioned, tens of thousands died. The heat wave only ended with a torrential rainstorm that caused renewed flooding, killing thousands more.

There was no relief. And death was everywhere.

Worldwide polling suggested mounting confusion, frustration, and despair. Decarbonization efforts seemed to be advancing quickly. Warming appeared on track to stabilize below 2.5 °C, relative to Earth's average temperature in the late 19th century. The global community had finally gotten serious about solving climate change.

Yet the impacts of global warming seemed to be escalating. Disasters were multiplying, and increasingly connected. People were dying in unprecedented numbers.

Some of the most frightening transformations happened out of sight, at the poles.

In the early 21st century, the Greenland Ice Sheet was already losing some 264 billion tons of ice per year. But in 2061 alone, AI systems estimated that nearly 1 trillion tons had been lost.

Owing both to water melting from ice sheets into the oceans, and to the expanding volume of warmer water, sea levels were now more than a foot higher than they had been at the start of the 21st century. Regular flooding at high tide was beginning to require permanent evacuations in many countries.

Worse, the Atlantic Ocean currents that stabilize Earth's climate seemed to be weakening. These currents, known collectively as the Atlantic Meridional Overturning Circulation (AMOC), had long pushed warm, salty water from the equator to the North Atlantic. As the water moved north, it got colder, and because it was especially salty, it was dense. It sank into the deep ocean, cooled, then returned south.

For thousands of years, the salinity of cooling water from the tropics had kept the AMOC moving. Now, the water was beginning to stay warm. And freshwater melting off the Greenland Ice Sheet was making it less salty.

AI forecasters predicted that the AMOC was poised to slow down dramatically – a possibility that climatologists had been warning about for decades. Because winds blowing from the west over the warm, salty currents of the AMOC gave Europe its mild climate, an AMOC slowdown tantamount to a collapse threatened to abruptly cool the continent, at least during the winter.

By rerouting the circulation of the atmosphere, an AMOC breakdown also threatened to catastrophically weaken the monsoons that provided life-giving rains across Africa and Asia. A multiple breadbasket failure would become a permanent reality. Hundreds of millions, perhaps billions of lives were at risk.

Governments had waited too long to slash greenhouse gas emissions. Decarbonization, by itself, no longer felt like it could prevent a global demographic and economic collapse.

2061-64: Geoengineering Offers a Lifeline

With no time to spare, some governments funneled tens of billions of dollars into ambitious *geoengineering* experiments.

Geoengineering is a deliberate, large-scale intervention in Earth's climate system that counteracts global warming. Such interventions had been simulated using computer models but never tested on a scale that could actually induce local cooling – partly because real-world experiments raised public concerns about tampering with the atmosphere.

Now, the risks seemed worth it.

Solar radiation modification (SRM) appeared to be the most promising approach to geoengineering.

One version of SRM, known as *stratospheric aerosol injection* (SAI), would inject aerosols – particles or droplets suspended in air – into the stratosphere, where they'd form particles that scattered a small fraction of incoming sunlight back into space. The stratosphere would warm up, but the lower atmosphere would cool down. SAI seemed like the geoengineering method that would be easiest to deploy and most likely to work at scale, because it roughly copied how explosive volcanic eruptions had long cooled the Earth.

But a series of experiments that released aerosols into the stratosphere confirmed what climate models had long simulated: SAI not only lowered temperatures, it also reduced evaporation and redirected prevailing winds in ways that increased the intensity of droughts in some regions, such as West Africa, even as it eased droughts elsewhere.

Both the African Union and the European Union therefore joined governments across Oceania and South Asia in supporting intensified research into other forms of geoengineering. Scientists experimented with *marine cloud brightening* (MCB), an SRM technique that sprays a fine seawater mist into the air beneath ocean clouds. As the mist evaporates, it leaves microscopic salt particles around which water condenses, creating more and smaller cloud droplets. The droplets make clouds more reflective, reducing the sunlight that reaches the ocean.

Sustained experiments confirmed that MCB could modestly lower sea-surface temperatures. And as expected, cooling was strongest near the treated clouds.

Geoengineering had long been a fringe idea. For decades it had been promoted by a group of outspoken scientists, engineers, and policy professionals – even as it was condemned by most climatologists and environmentalists, and rejected by many governments. Public opinion was divided, and popular opposition had thwarted early attempts at geoengineering experiments.

But by the early 2060s, a once-marginal idea seemed increasingly inevitable. Governments agreed that the climate would either be geoengineered or it would break down, destroying ecosystems – and perhaps humanity – forever.

In the end, it wasn't a difficult choice.

2064-2080: Geoengineering Stops Global Warming

On March 17, 2064, after months of negotiation with European and North American allies, the Danish government authorized the world's first sustained MCB deployment.

A small fleet of retrofitted Royal Danish Navy vessels began operating west of Greenland, dispersing a fine mist of seawater into low-lying marine clouds. The goal was not to reverse global warming, but to locally reduce incoming solar radiation and thereby slow the loss of ice from the Greenland Ice Sheet.

After decades of modeling, laboratory work, and limited field trials, MCB had become technically viable.

Public opinion began to shift. A generation shaped by waves of deadly and unprecedented climate shocks was willing to accept deliberate alterations of the atmosphere that promised to cut the risk of extreme weather. Even those who feared the unintended side effects of geoengineering were more likely to condemn previous generations for their inaction than to criticize present efforts to directly stabilize the climate.

Early results were modest – but noticeable. Within a few years, regional surface temperatures in parts of the North Atlantic stopped rising, then started to decline. The rate of ice loss from some Greenland outlet glaciers slowed down. There were also tentative signs that the AMOC was no longer weakening with the same speed.

But the side effects were quickly apparent. Changes in cloud cover altered regional energy balances in ways that extended beyond the deployment zone. Climate models had long suggested that modifying clouds in the North Atlantic could shift atmospheric circulation patterns, and by the mid-2060s, rainfall across parts of West Africa had declined measurably. The signal was difficult to separate from existing climate variability, but the trend was persistent enough to trigger political alarm.

West African governments had opposed SRM precisely because it could reduce regional rainfall. Now, the MCB efforts they had initially supported seemed to generate a similar result. Supported by international advocacy groups, many began pressing for compensation and formal oversight mechanisms.

New disputes fed into a broader and increasingly urgent debate over the "law of the atmosphere." Who had the authority to alter shared climatic systems? Could regional coalitions deploy interventions with global consequences?

By the late 2060s, negotiations over governance frameworks threatened to derail the Danish MCB effort. Yet AI systems were eventually able to quantify the relationship between MCB and regional droughts – at least, enough to satisfy many governments. Since the relationship turned out to be modest, compensation could be worked out through the Geneva Climate Compact.

Now the MCB sector expanded rapidly. By 2070, hundreds of firms, ranging from small startups to major engineering consortia, were developing dispersal systems, modeling platforms, and monitoring tools.

Some MCB efforts focused on ecosystem protection. Across the remnants of the Great Barrier Reef, for example, Australian-led projects used MCB deployments to reduce peak water temperatures during marine heatwaves. The frequency and severity of coral bleaching declined, raising hopes that parts of the reef could be restored by the end of the century.

Elsewhere, larger deployments followed. A U.S.-backed consortium began operations over parts of the Southern Ocean, aiming to reduce heat uptake near Antarctic ice shelves. Over time, observations suggested a slight reduction in melt rates in some vulnerable regions, though attribution remained contested.

In 2072, Japan and South Korea launched the Pacific Cooling Initiative, coordinating MCB operations in several persistent stratocumulus cloud zones. The program became an early example of sustained regional cooperation in climate intervention.

Innovation and deployment of technologies that directly pulled carbon dioxide out of the atmosphere advanced more slowly, but with fewer geopolitical risks.

In 2073, China announced the first large-scale deployment of its CarbonBox direct air capture (DAC) systems, powered by decades of investment in low-carbon energy. These facilities used chemical processes to extract carbon dioxide from the atmosphere, storing it underground or converting it into industrial *feedstocks*: raw materials that could be used to create finished products. The advent of largescale DAC seemed to represent a shift toward addressing the root cause of warming, rather than its immediate symptoms.

By the late 2070s, MCB efforts altered cloud cover above some 12% of the world's oceans, in key regions that were most vulnerable to warming. The net global cooling effect amounted to a few tenths of a degree Celsius.

It was a small number, but it bought crucial time for ongoing decarbonization efforts. Not only did it preserve ocean ecosystems and currents; it allowed global temperatures to be stabilized at 2 °C above their average in the late 19th century. And because both the frequency and severity of weather extremes had been fueled not only by the *average* temperature of the planet but also by the planet's *rate* of warming, Earth was suddenly a less dangerous place.

In 2079, AI systems estimated that decarbonization and geoengineering had sharply lowered the risk of multiple breadbasket failures. The AMOC no longer seemed to be weakening. Sea levels were still rising, but the *rate* at which they were rising was expected to decline over the coming century.

Coastal ecosystems still needed restoration; sea walls had to be built or strengthened along the world's shores. But it seemed likely that many corals could be restored, and that future flooding would be manageable.

Still, all this progress hinged on continued international cooperation. Both geoengineering and decarbonization efforts would need to be sustained for decades, or the climate crisis would come roaring back – and billions could still die.

2080-2100: Phasing Out

As the geoengineering industry boomed, its critics multiplied – even as warming slowed down.

By the early 2080s, regulatory battles were unfolding in courts and international forums around the world. Governments struggled to define the legal boundaries of MCB, because AI systems estimated that the downstream effects of MCB on wind patterns and rainfall were becoming more severe. That made them ever harder to address through the Geneva Climate Compact.

In parts of West Africa, for example, seasonal rains declined over several consecutive years. Governments in the Global North could reimburse farmers for lost harvests, but did they also have to pay for rising food prices? And how could governments compensate for dust storms, or for migration from country to city?

AI systems also began to detect subtle but persistent changes in atmospheric chemistry, including modest regional fluctuations in ozone concentrations. These changes were not catastrophic – not yet – but they reinforced a growing sense that the climate system was being altered in ways that were dangerous and increasingly unfair.

Another concern loomed even larger: what would happen if MCB stopped.

Climate models had long warned of the possibility of a *termination shock*: a rapid spike in temperatures if geoengineering were suddenly halted while greenhouse gas concentrations remained high. The rise in temperatures could be much faster than it had been before geoengineering projects had been implemented. The weather extremes that had killed millions would return, worse than ever.

By the 2080s, this was no longer an abstract risk. Geopolitical tensions were rising, not least because of the perceived impacts of geoengineering on drought. A world war seemed increasingly plausible, and many found it unlikely that MCB could be sustained if and when hostilities broke out.

Then, in 2085, a truly severe drought spread across West Africa, devastating food and water systems that remained fragile. Regional governments blamed the drought on the Danish MCB operation in the North Atlantic, and demanded unprecedented compensation.

The perception of causation spread more quickly than the science, fueling international outrage. Regional governments banded together with governments across the Global South that believed their countries had been warmed by MCB efforts. Environmental activists accused wealthy nations of reshaping the climate in their favor, at others' expense.

The geoengineering sector responded forcefully, emphasizing the dangers of stopping MCB programs too quickly. AI advisors and scientists agreed: if MCB were to be reduced, it would have to be done gradually, over decades, with international coordination.

That conclusion led to a pivotal meeting in Seoul on November 17, 2087. Representatives from major powers, vulnerable states, and key scientific institutions convened to negotiate what became known as the Seoul Accords. They agreed to establish a 20-year framework for scaling back MCB operations, paired with continued emissions reductions and expanded carbon removal. They also created a new international body, the Global Climate Intervention Monitoring Agency, tasked with tracking atmospheric conditions in real time and adjusting interventions if warming exceeded agreed thresholds.

Equally important was the creation of a larger compensation fund, financed primarily by the governments and corporations that had led MCB deployment. The fund directed resources to regions demonstrably harmed by climate interventions, including much of West Africa.

The arrangement was contentious, particularly among private firms that had invested heavily in geoengineering infrastructure. Yet the alternative – a fragmented system of unregulated interventions, with the constant risk of conflict and abrupt termination – was now seen as fragile and dangerous.

In any case, by the 2090s, decarbonization efforts were beginning to remove the need for MCB interventions. Energy systems approached net zero emissions, meaning that humans no longer released more greenhouse gases into the atmosphere than they removed. Direct air capture had expanded, and now removed meaningful quantities of carbon dioxide from the atmosphere.

Agricultural systems had also adapted, with drought-resistant crops and large-scale reforestation helping to stabilize the bread baskets. Coastal cities, including places like Charleston, had fortified themselves against flooding and storms.

The world of 2100 is no paradise. Ice sheets continue to lose some mass. Ecosystems remain under pressure. But warming has slowed and, for the first time in generations, global temperatures seem to have stabilized – at around 1.5 °C above pre-industrial levels.

Exactly where they stood some 75 years ago.

2100: Back From the Brink

Looking back, it's clear that geoengineering could not, by itself, "solve" the climate crisis. The only way to do that was to lower concentrations of greenhouse gases in the atmosphere.

But geoengineering *could* buy time, a precious reprieve from the escalating consequences of global warming. Because it was also a precarious reprieve, much depended on what was done with it.

Fortunately, governments around the world created powerful incentives for renewable energy, electric vehicles, low-carbon industry, and regenerative agriculture. As investment poured into new technologies and practices, the green economy expanded at extraordinary speed.

Fewer people died from airborne pollution. The oil-driven conflicts of the twentieth and early twenty-first century were a distant memory.

And greenhouse gas emissions began to fall. Eventually, atmospheric concentrations stabilized, then slowly declined.

It was enough. The reprieve provided by geoengineering may have saved billions of lives, and perhaps humanity's very future. It gave societies the breathing room they needed to complete a transition that could otherwise have come too late.

It's strange to think that, if recent history had unfolded just a bit differently, Earth would be a totally different planet today. A planet heating too quickly for societies to adapt, not to mention the plants and animals on which human life depends.

Millions, perhaps billions might already be dead.

Maybe a second storm like Celeste would have torn through South Carolina. This time, nobody would have been around to rebuild. I might not have been born.

And another student – halfway around the world, perhaps – would have written a very different essay.

Geoengineering Catastrophe, 2046-2100

Name: Faisal Al-Jasser
Date: April 29, 2100
Professor: Rayan Al-Qahtani
Location: King Abdulaziz University, New Buraidah Campus

Introduction: A Failed Experiment

These days, in Buraidah, Saudi Arabia, summer temperatures regularly exceed 50°C.

By late morning, the streets are empty. Outdoor work is impossible. Even short walks can be deadly – especially in humid weather when the body can no longer cool itself through sweat.

Every summer, thousands die.

This was not my parents' world. I was born in Jeddah, on the Red Sea coast, where my family owned a small resort. In my earliest memories, the sea still felt alive. But by the time we left, the reefs had turned white and brittle. The water had grown uncomfortably warm, and the shoreline flooded during high tides.

We left in 2091, when I was eleven. I still remember: some of our neighbors said the heat would pass. They said the world had already solved climate change once, and that it would do so again. They believed that the crisis we were living through couldn't last.

They were wrong.

What we lived through was something scientists had long warned about. A *termination shock*, an abrupt surge in global temperatures following the collapse of a geoengineering program. One that had cooled the Earth even as greenhouse gases continued to add up in the atmosphere.

That phrase, "termination shock," can't capture what it felt like.

The heat didn't simply return. It arrived in devastating, utterly unprecedented heatwaves and droughts. The rate of warming was *seven times* higher than it had been during the 2046 Great Hunger. This time, the death toll can be measured in the hundreds of millions, perhaps the billions – at least if early estimates are to be believed.

Humanity is on the brink. And to understand why, you have to begin in 2046, when governments agreed to cool the planet not by reducing emissions, but by dimming the Sun.

2046–2051: The Quick Fix

After the Great Hunger, governments faced a terrifying reality: the global food system had failed under conditions that scientists had long warned were possible when warming approached 2°C, relative to the world's average temperature in the late 19th century.

Multiple breadbasket regions had experienced simultaneous drought and heat. Harvests failed everywhere. There was no surplus to compensate. Tens of millions died, governments collapsed, and global trade broke down.

At the emergency United Nations session that followed, there was widespread agreement that conventional climate policy had not been sufficient to prevent catastrophe. AI systems estimated that even an implausibly aggressive campaign to reduce emissions could not prevent the likely recurrence of multiple breadbasket failures. And no amount of adaptation – genetically engineering more drought-resilient crops, for example, or investing in indoor, controlled-environment agriculture – seemed sufficient.

Attention therefore turned to geoengineering: deliberate, large-scale interventions in Earth's climate system to slow down or even reverse global warming.

Policymakers weighed two approaches. The first involved removing greenhouse gases from the atmosphere. Options included scaling up technologies like direct air capture, which uses chemical processes to pull carbon dioxide out of the air, or growing trillions of trees. The advantage of this approach was that it would actually address the most important cause of global warming: carbon dioxide concentrations in the atmosphere.

But it was quickly apparent that, despite decades of investment, carbon dioxide removal infrastructure could not scale up quickly enough to counteract the vast emissions of greenhouse gases still pouring into the atmosphere. Owing to increasingly severe forest fires and the spread of wood-boring beetles in warming weather, many forests also released more carbon dioxide than they absorbed. And even the world's most capable AI models could not confirm that exotic carbon dioxide removal possibilities – such as a plan to fertilize the oceans with iron to encourage the reproduction of carbon-absorbing plankton – could actually work.

The second approach involved changing how much sunlight the Earth absorbs. The rapid growth of the space industry over the past three decades led some to suggest that it was now possible to install a swarm of tiny sunshades at L1, the so-called first Lagrange point, where the gravitational pull of the Earth and Sun balance each other. The swarm would block a tiny fraction of incoming solar radiation, enough to counteract the warming effect of greenhouse gas emissions. And because the gravitational fields of the Earth and Sun counteracted each other so perfectly, the swarm could remain in place with minimal intervention.

But enthusiastic support for the plan by controversial tech entrepreneurs, combined with the vocal opposition of influential climatologists, led to intense public skepticism about the feasibility of a sunshade swarm. Governments therefore turned to another possibility for reducing incoming solar radiation: *solar radiation modification* (SRM).

A form of SRM called *stratospheric aerosol injection* (SAI) seemed promising because it replicated a proven mechanism for cooling the climate: the eruption of explosive volcanoes. Such volcanoes hurl sulfuric gases into the stratosphere, the layer of the atmosphere above weather systems. There, the gas forms tiny reflective particles – sulfate aerosols – that scatter and absorb sunlight. The particles, known collectively as a volcanic dust veil, reduce the amount of solar energy reaching Earth's surface, temporarily cooling the planet.

It was easy for activist scientists to sell SAI to policymakers and the public because they could argue that it simply reproduced a natural process. Aircraft would fly 18 to 22 kilometers above sea level, releasing sulfur dioxide into the stratosphere. Winds would spread the resulting aerosols around the globe, forming an artificial dust veil.

Because these particles would remain in the stratosphere for only about one to two years, SAI could easily be abandoned if it didn't work, or if its side effects proved too severe. Of course, if it *did* work, it would require constant replenishment.

The attraction of SAI was not just that it seemed like a proven method for cooling the Earth. It was also the speed at which it seemed capable of lowering global temperatures. Unlike emissions reductions, which could take decades to clearly impact worldwide temperatures, let alone a swarm of miniature spacecraft, which would take many years to manufacture and position, SAI could produce measurable cooling within months.

Climatologists warned that SAI would also create profound new risks.

Climate models – computer simulations of Earth's climate – had long indicated that SAI could dry out some regions, even as it restored moisture to others. By lowering rates of evaporation, SAI promised to keep more water in the soil across many of the world's breadbaskets. But with less evaporation, less water would enter the atmosphere, while a colder atmosphere could also hold less water.

Models simulated that over much of central Africa, for example, less rain would fall in a world geoengineered with SAI. Monsoon systems, which depend on temperature contrasts between land and water, also seemed likely to weaken during an SRM program, as aerosols cooled land more efficiently than water.

Still, the droughts created by SRM were more local in scale, and overall weaker in intensity, than those associated with rapid global warming. SRM therefore seemed like an obvious choice – but for two other, seemingly more serious risks.

First, sulfuric gases would eat away at the ozone layer, which protects the DNA in plants and animals from the Sun's most energetic ultraviolet radiation.

SAI that used sulfur – the obvious choice, given the proven capacity of sulfur to cool the Earth after volcanic eruptions – was risky to maintain for longer than a few decades. A worldwide ozone hole would make it dangerous to stay outside. By damaging plants and plankton, accelerating the breakdown of decaying vegetation, and altering the circulation of the atmosphere, it would likely lead to a rise in greenhouse gas emissions that could, ironically, warm the Earth.

Second, SAI would be dangerous unless it coincided with unprecedented efforts to slash greenhouse gas emissions and expand investments in carbon removal technology.

Without these efforts, greenhouse gases would build up in the atmosphere. If anything were to disrupt SAI operations – a major war, for example – or if the damage to the ozone layer became too great, then SAI could be stopped while greenhouse gas concentrations were at least as high as they were in the late 2040s, and perhaps much higher.

Earth's temperature would then rise with a speed that perhaps no human or natural system could endure. This termination shock meant that any SAI operation was fraught with peril.

Still, after the Great Hunger, governments leapt at the opportunity to fix the climate. SAI was all the more attractive when AI systems estimated that governments could carry it out at a cost they would scarcely notice.

It seemed like a classic case of spending billions to save trillions. And it quickly attracted broad public support. Politicians who expressed doubt were voted out of office, or forced to change their minds. Even in authoritarian states, the fear of a popular uprising led governments to support rapid action.

It was time to dim the Sun.

2051–2054: The First Geoengineering Efforts

The first large-scale SAI program launched in early 2051, as climate models – refined and interpreted using increasingly powerful AI systems – again hinted at the emergence of a strong El Niño.

A UN resolution, opposed only by the governments of Ecuador, Bolivia, and Equatorial Guinea, authorized an effort, led by the US Air Force, to inject aerosols into the stratosphere above the tropical Pacific Ocean.

The stratosphere begins at a very high altitude around the tropics, since warm air occupies more volume. Existing tankers couldn't reach such heights. The Air Force therefore commissioned Northrop Grumman, a defense contractor that had already built high altitude drones, to construct an automated, purpose-built tanker – the MQ-32A Stratus – using designs engineers had proposed decades earlier.

Officials at the Department of Defense had worked hard to streamline the process of commissioning and deploying new systems. And in March 2051, the first fleet of 80 Stratus drones dispersed sulfur dioxide into the upper atmosphere.

Although they'd been constructed in record time, neither scientists nor AI systems could be sure that they'd launched quickly enough to avoid another super El Niño. El Niño *did* develop later in the year – but it was milder than feared. AI systems soon estimated that the Air Force's SAI program had meaningfully reduced its severity.

At the cost of just under ten billion dollars – for the design, construction, and initial deployment of the drones – countries around the world seemed to have avoided incalculable harm to lives, livelihoods, and the global economy. And perhaps another Great Hunger.

The apparent success of temporary SAI efforts in the Pacific led to unanimous support for a UN resolution that authorized a permanent SAI program in the Arctic.

The region was now about 8°C hotter than it had been in the late 19th century. When Arctic sea ice reached its annual minimum in late September, it covered less than half the area it had in the 2020s. Regional ecosystems seemed on the cusp of irreversible change.

The accelerating melt of the Greenland Ice Sheet was a major contributor to the worldwide rise in sea levels. Worse, meltwater pouring off the ice sheet was weakening currents in the Atlantic Ocean, which in turn threatened to upend the circulation of air across the northern hemisphere. If that happened, climate models forecast wild seasonal contrasts in Europe, much weaker monsoons in Africa and Asia – and harvest failures that could dwarf those of the Great Hunger.

Companies that had constructed military and transport drones now built fleets of specialized, high-altitude sulfur dispersal platforms. Operated by NATO air forces, these drones used bases across northern Canada, Greenland, Iceland, and Norway. Flights operated continuously and autonomously, guided by a dedicated AI that used a satellite constellation to coordinate their efforts in real time.

Within months, satellites measured a significant increase in stratospheric aerosol concentrations over the Arctic. By 2052, surface temperatures in parts of the Arctic had declined by more than one degree Celsius. That September, sea ice covered more territory during its annual minimum than it had since 2027. There were even promising signs that melt rates had declined along the periphery of the Greenland Ice Sheet.

Encouraged by these results, an international coalition, led by India, launched an expanded SAI operation from bases in Indonesia.

For thousands of years, explosive volcanoes that cooled the Earth had often erupted in Indonesia. It wasn't just that the collision of tectonic plates spurs volcanism across Indonesia; it was also that, in the tropics, air rises and moves towards *both* poles. Aerosols that formed above Indonesia and other equatorial countries therefore ended up in both hemispheres, which meant that they could cool the entire globe.

The Indonesian SAI effort used the same methods as the Arctic program, but its scale was even larger. In October 2054, AI systems confirmed that Earth's average temperature was no longer rising. Some places even seemed to be cooling.

In just two years, SAI had stopped a warming trend that had continued for nearly two *centuries*.

2054–2065: The Illusion of Stability

For some, there was an obvious parallel with the COVID-19 pandemic, more than 30 years ago, and the course of global warming in the 21st century.

Governments had not been able to prevent the *spread* of the pandemic, and they had not been able to stop the accumulation of greenhouse gases in the atmosphere. Yet in the face of death on a truly global scale, governments and corporations *had* developed tools that could mitigate the *effects* of disease – and warming. Vaccines had helped end the pandemic. Now, it seemed that SAI had ended global warming.

There was a wave of popular optimism. There was even a baby boom that, in many countries, temporarily reversed declining fertility rates.

In 2055, at the 60th Conference of the Parties (COP) of the UN Framework Convention on Climate Change, governments agreed to a target for average global temperatures: 15°C. That was about 1.3°C hotter than the preindustrial average, and roughly where global temperatures stood in 2020. COP60 also established the monitoring mechanisms that would harmonize the Arctic and Indonesian SAI efforts, ensuring that they would, together, set the global thermostat at its new target temperature.

The reduction and then stabilization of Earth's average temperature reshaped climate politics. If the climate could be cooled artificially, popular politicians argued, then greenhouse gas emissions were no longer an urgent problem. The energy transition could unfold at a natural pace, without the urgent and often costly emergency measures that climate activists had called for.

This dynamic is often described as *mitigation deterrence*. As climate scientists had long warned, geoengineering reduced the incentive to reduce emissions.

Here in Saudi, the consequences were immediate. Oil demand surged. Revenues increased dramatically. Infrastructure expanded. Jeddah became a global hub for tourism and finance.

And in 2060, my family opened our resort on the Red Sea coast.

Globally, similar patterns emerged. Fossil fuel production expanded. Coal plants, once scheduled for demolition, remained in operation. Investment in renewable energy faltered. Even electric vehicle adoption plateaued.

Powerful geopolitical forces re-emerged. Representing the world's leading oil and natural gas producer, the United States government pressured states to moderate or abandon their decarbonization targets. The US had long since ceded the renewables, battery, and EV industries to China; now, SAI offered a way to regain leverage over the global energy system.

Even American or Saudi policymakers were, of course, aware that SAI could only temporarily reverse global warming. But a decades-long solution to the problem felt eternal when elections – or street protests – were always a couple of years away.

More importantly, SAI restored faith in the idea that humans, aided by superhuman AI systems, could innovate technological solutions to any problem. According to public opinion polls, many believed that when it was finally time to roll back SAI efforts, there would be another, better, geoengineering option that would stabilize global temperatures for good.

By the early 2060s, atmospheric concentrations of carbon dioxide approached 550 parts per million (ppm), compared to nearly 430 ppm in 2026 and about 290 ppm in 1880. Maintaining global temperatures required ever more atmospheric injections of sulfur dioxide. Without the drone flights from Arctic and Indonesian airfields, accumulating greenhouse gases would have rapidly and irreversibly transformed the Earth into a much hotter and less habitable planet.

Of course, SAI did not just preserve Earth as we knew it. As decarbonization efforts stalled, it became a vehicle for global inequality. It sustained the profits of oil companies, and upheld the geopolitical power of oil producers.

It was a recipe for exactly the kind of global division that could bring SAI to a premature end.

2065–2075: A Climate Divided

By the late 2060s, the side effects of SAI were increasingly visible.

With aerosols abundant in the stratosphere, deep blue skies were increasingly rare. Fewer stars were visible in the night sky. This was mostly an aesthetic loss, and less obvious in light-polluted cities. But to varying degrees, it affected everyone. Polling suggested that, by the late 2060s, it helped kindle a new and increasingly widespread unease with SAI efforts.

More tangible was the weakening of monsoon systems, more or less as climate models had simulated. In South Asia, the consequences could be severe.

The 2068 Indian Summer Monsoon arrived late and weak. Far less rain than expected fell across northern India and Pakistan. Reservoirs couldn't be replenished, and crop yields collapsed.

Yields were higher than average in the United States, so global food prices didn't increase dramatically. Still, prominent politicians in India's Aam Aadmi Party – then its official opposition – demanded to know why India would lead an SAI program that seemed to disproportionately benefit Americans.

These demands grew louder and attracted growing public support in 2069 and 2070, when the monsoon remained weak. By 2071, large parts of the Indo-Gangetic Plain had experienced consecutive crop failures. Wheat and rice production had dropped sharply, while regional food prices surged.

AI models estimated that India had spent billions on an SAI program that had inflicted *tens* of billions in damage through weakened monsoons. Those same models were not asked to calculate the potential cost to India of global warming had SAI programs *not* been implemented. Nevertheless, the results spurred even more widespread outrage, and – increasingly – violent protests in Chandigarh, Ludhiana, Meerut, and other cities across Punjab, Haryana, and western Uttar Pradesh.

At the same time, West Africa entered a prolonged drought. Rainfall in the Sahel declined dramatically over several consecutive years. Pastoral communities lost livestock, while farmers abandoned fields. Widespread malnutrition worsened outbreaks of epidemic disease, including two caused by previously unknown pathogens.

Migrants poured into coastal cities and across borders into North Africa, sparking bloody conflicts that incited sporadic violence between states. By 2073, hundreds of thousands had died amid food shortages, disease outbreaks, and conflict that AI models could clearly link to the effects of SAI programs.

Responding to popular pressure, governments demanded compensation for the impacts of droughts. A common target was the United States, which both led the SAI program in the Arctic and benefitted from continued oil and gas production. Ironically, the Indian government both demanded compensation and defended itself against claims for damages caused by the Indonesian SAI effort.

These claims multiplied. By 2075, politicians blamed every major drought on SAI efforts, even when AI models couldn't firmly establish a relationship between those droughts and SAI programs. The argument was simple, and ultimately persuasive. Because the climate had been altered by geoengineering, popular politicians argued, extreme weather that occurred within that climate – especially drought, which climate models had already connected to SAI – was automatically a product of geoengineering.

The American government countered demands for compensation by pointing out that it had shouldered the majority of the cost – and provided most of the equipment and expertise – for the Arctic SAI program. If anything, *it* deserved to be paid for the estimated damage that would have occurred *without* geoengineering. And AI systems calculated that this damage would be in the tens of trillions of dollars, given current greenhouse gas concentrations.

When governments in drought-stricken countries continued to demand compensation, the governments most responsible for SAI efforts – led by the United States – repeatedly threatened to suspend their operations. Relations quickly soured between countries that were perceived to benefit from SAI and those that were viewed as suffering, and between countries that contributed to SAI efforts and those that didn't.

The stage was set for the catastrophe that shattered the geoengineering experiment – and triggered warming unlike any in human history.

2075–2080: The Aerosol War

In 2075, threats by the United States to abandon the Arctic SAI program intimidated governments across Eurasia and Eastern Africa, where temperatures or precipitation would suddenly change if Atlantic ocean currents abruptly weakened. Many dropped their demands for compensation.

Their retreat only emboldened the Americans. The renewed growth of fossil fuel extraction and consumption had led to a widespread perception that the United States was again the world's leading power, following an interval in which China seemed ascendant. Owing to the relationship between the circulation of the air and oceans, the American-led SAI effort also seemed to provide fewer benefits in North America than it did elsewhere.

The leverage provided by American power, on the one hand, and global circulation, on the other, seems to have convinced the American President – or the AI system advising the President – to demand back payments for nearly 25 years of geoengineering the Arctic. When governments refused to pay, the United States suspended drone flights for a week.

Frantic negotiations followed. Despite widespread and occasionally violent protests, many governments agreed to compensate the United States by purchasing vast quantities of American oil and liquefied natural gas, and investing trillions in US energy companies, pipelines, refineries, and petrochemical infrastructure.

The success of these negotiations – from the perspective of the US government – inspired a newly elected Indian government, led for the first time by the Aam Aadmi Party. India's Prime Minister called for a second investment scheme that would both compensate India for its leadership of the Indonesian SAI effort, and pay for damages tied to the related weakening of the monsoon. To create leverage, in 2076 the Indian Air Force followed the American example by suspending its SAI operations, this time for two weeks.

Once again, governments responded with panic. But unlike in 2075, panic did not prompt negotiations or concessions.

China had long vied with India for influence across Asia. Its rapid demographic decline, prompted in part by the One Child Policy of the 1980s, 90s, and early 2000s, had weakened its position relative to both the United States and India. Now, the Chinese government – advised by the world's most capable AI model – perceived an opportunity to undermine India's relationships with governments not just in Asia, but around the world.

China's President announced that China would not accept blackmail that used the stability of the world's climate as leverage. It announced that it would soon undertake its own SAI program from artificial airfields in the South China Sea. Chinese officials insinuated that an SAI effort was too expensive for India to maintain – but not for China.

The Chinese announcement seemed to improve China's position in the court of global public opinion. Like the initial demands for compensation involving India, there was an irony in this development. China had long been accused of freeriding by *not* participating in SAI efforts. Now, it was widely perceived as the only superpower responsible enough to prioritize climate stability.

The Chinese announcement was not only deeply embarrassing for the Indian government and damaging to India's global influence; it also threatened a key election promise by Aam Aadmi politicians. They had promised to use the leverage created by the Indonesian SAI program to secure massive foreign investments in Indian agriculture, not to mention direct cash transfers to low-income families who had struggled with high food prices. Now, it seemed they could not fulfill their promises. The era of Aam Aadmi dominance in Indian politics appeared to be ending almost before it could begin.

Believing it had no other options, the new Indian government threatened to intercept Chinese drones as they injected sulfur dioxide into the stratosphere. Indian officials did not believe that attacking uncrewed, autonomous drones would be perceived by their Chinese counterparts as an act of war. But China's global prestige was now tightly bound to its promised SAI efforts.

When the Chinese SAI program began in early 2077, and the first Chinese drones were destroyed by Indian interceptors, nationalist protests swept across China. In the face of popular pressure and the prospect of global humiliation, China's President announced that the Chinese Air Force would aggressively defend its SAI program – if necessary, by striking the airfields used by Indian interceptors.

It was the beginning of what commentators eventually called the Aerosol War. And it soon expanded beyond the worst fears of both Indian and Chinese officials.

For decades, the increasingly capable militaries of each superpower had prepared for war. As American influence receded from Asia in the late 2020s and 2030s, both the Indian and Chinese governments had constructed their own web of allies and dependents. Now, longstanding plans were put into practice. Aerial interceptions quickly escalated into long-range bombardment, border clashes, and finally all-out war between rival alliance systems.

To deprive India of any postwar leverage, the airfields and drones associated with the Indonesian SAI program were destroyed by Chinese bombers. Chinese airfields and drone infrastructure, meanwhile, were crippled by Indian bombers. For over a year, the war continued to escalate, with hundreds of thousands of casualties, until the destruction of an Indian flotilla raised the prospect of a nuclear exchange.

Owing in part to closely coordinated pressure by the American and Russian governments, the Chinese and Indian militaries stepped back from the brink. In late summer 2078, negotiations hosted by the Nigerian government culminated in an inconclusive settlement that, in some respects, restored the prewar status quo.

But the damage to the world's geoengineering efforts was complete. It was not just that the infrastructure upholding the Asian SAI program – which had stabilized the temperature of the entire world – had been destroyed. It was that SAI seemed to have brought governments to the brink of nuclear war.

The risks of SAI now appeared to outweigh its benefits. Public opinion turned sharply against the remaining SAI program in the Arctic. Governments that had once paid the United States to continue the program now demanded it be cancelled.

In 2080 – the year I was born – NATO allies formally terminated their SAI efforts in the Arctic. And at COP85, governments resolved to abandon the 15°C global temperature target. Politicians announced that humanity would no longer play God with the world's atmosphere.

It was a popular message. But at least some politicians must have known that it was too late to *stop* playing God.

Because atmospheric carbon dioxide concentrations now stood at 676 ppm.

2080–2100: The Termination Shock

By the end of 2080, AI monitoring systems determined that aerosol concentrations in the stratosphere were in rapid decline. The following year – 2081 – was the hottest in more than two decades. But it was nothing compared to the heat that awaited us.

In the following five years, global temperatures surged by nearly 1°C. That was as much as they had increased in the roughly *35* years preceding the Great Hunger of 2046.

I can't imagine what it was like for my parents to have a child in those years. Because weather extremes are caused not just by the average temperature of the Earth but also by the rate at which the temperature *changes*, heatwaves, torrential rains, droughts, and storms were truly unprecedented in their severity and frequency.

Well beyond the tropics, and for weeks at a time, extreme combinations of heat and humidity pushed wet-bulb temperatures – a measure of how effectively sweat can cool the human body – to levels that made it impossible to survive for more than an hour or two. Like many cities, Jeddah became unlivable in the summer. Then, in 2084, harvests failed across all of the world's breadbaskets, sending food prices to new highs. They failed again in the following year.

It's impossible to overstate the magnitude of these disasters. By 2085, hundreds of millions may have died. It wasn't just the famine. It was the heat itself. People without air conditioning simply couldn't survive. And even where there *was* air conditioning, the electrical grid often couldn't hold up.

Governments scrambled to respond. Trillions of dollars flowed into controlled-environment agriculture, including vast vertical farm complexes. Robots were able to build these complexes quickly, even in blistering weather, while AI systems developed even more capable, drought-resistant crops to grow outdoors.

The world's food system briefly recovered. But, in 2088, measurements by satellites and ocean buoys confirmed that Atlantic Ocean currents were finally collapsing. Dramatic shifts in temperature and precipitation transformed the world's breadbaskets, and profoundly reduced the amount of land on which staple crops could be grown. Even when spearheaded by AI systems with inhuman abilities, adaptation efforts could not compensate for the loss.

By 2094, governments around the world imposed draconian food rationing measures. Many limited meat consumption, restricted purchases of staple grains and cooking oil, and issued digital ration credits that capped how much families could buy each month. In most countries, the penalties for defying these edicts included death.

Human life, after all, seemed increasingly cheap.

Ecosystems across the tropics were now in headlong collapse. Forest fires raged on a continental scale, lofting vast plumes of carbon dioxide into the atmosphere. Methane – on short timescales, an even more potent greenhouse gas – surged out of the deep oceans and the melting permafrost.

A rapidly heating world created the mechanisms to heat itself ever faster, and faster.

The collapse of Atlantic Ocean currents reduced the northward flow of heat from the tropics, and that slowed the melting of the Greenland Ice Sheet. Yet the melting of the West Antarctic Ice Sheet accelerated until, in 2095, cliffs holding back the ice abruptly gave way. Vast quantities of ice, inconceivable in scale, rushed into the Southern Ocean. In just the last five years, sea levels have increased by 20 centimeters.

Climate models simulate that they will rise by another meter, at least, in the coming two decades. If the entire West Antarctic Ice Sheet melts – which now seems inevitable – sea levels will eventually climb by ten feet.

2100: A Doomed World?

Today, at the turn of the 22nd century, the world is defined by displacement.

Hundreds of billions, perhaps billions have died. It's impossible to know exactly how many. And hundreds of millions more are on the move.

There is no future in the countryside, so they move to the city. There is no future along the coast, so they move inland. The trouble is that the cities are on the coast, while the countryside is inland.

So where do people go? For millions, the answer is grim. They go to their graves. There is no escape.

Except for the machines. They build where and when we no longer can. They construct greenhouses, vertical farms, and cities where life is still possible for most of the year. For now, at least, they build for us. But increasingly, they look like the future of life on this plant.

I hope that we can share in that future. But the prospects seem dim.

Looking back, geoengineering worked – for a time. It cooled the planet. It prevented immediate catastrophe. But it also changed how people thought.

Instead of reducing emissions, governments learned to tolerate them. Instead of solving global warming, they managed its symptoms. They built a system that required constant global cooperation, something history has rarely sustained.

When the system failed, everything failed with it.

Perhaps, in Saudi, we've come full circle. The wealth we gained from warming the Earth was consumed by warming.

The oil economy has finally collapsed. Many cities are uninhabitable. Towns in northern regions, far from the coast, have become refuges, not because they’re safe, but because they seem habitable. At least for part of the year.

My family moved north in 2091. We hoped it would be temporary.

It wasn’t.

A World Stabilized Below 3 °C, 2046-2100

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Introduction: A City Left Behind

I was born in what was once the largest city in the world.

About 75 years ago, in late 2025, the United Nations estimated that nearly 42 million people lived in greater Jakarta. My grandparents remember an endless sprawl, brimming with energy, full of every sound and smell. Trains were crowded at dawn, roads were thick with cars, and sidewalks were all but impossible to navigate.

I was eleven when my family abandoned Jakarta for Nusantara, Indonesia's new capital on Borneo. By then, Jakarta's northern districts flooded so often that maps changed from year to year. Pumps and sea walls protected some streets, while the waves consumed others.

Jakarta didn't die. It was mutilated.

As people left, many neighborhoods were abandoned. Others were fortified against the waves. The city became even more unequal. Some blocks still resembled their old self. But not far away, others were empty, filled with crime – or water.

Soon, Jakarta was a shell of the city my grandparents were so proud to call home.

Today, global warming has finally leveled off. Earth's average temperature is just under 3 °C higher than it was in the late 19th century.

That number sounds small. But it's averaged across the entire planet, over multiple years. Much more warming has happened over land than in the water, or in the Arctic than at lower latitudes. Every summer brings deadly heatwaves, unprecedented floods or droughts, and cyclones that strengthen with terrifying speed.

But I often think that if the climate scientists who warned of catastrophe, a century ago, could see our world, they might have been relieved.

After all, industrial civilization *has* endured. Food production has recovered. Global greenhouse gas emissions have fallen to roughly net zero. Temperatures have stopped climbing. And the world's population stands at about 10 billion.

There's reason to hope that, after a century of crisis and decline, the coming century will be one of recovery and relief.

But the drowned streets of my hometown remind us that some things can never be restored. And that many who lost the most often could least afford to lose it.

This is a history of how humanity stabilized the climate – belatedly, when it was almost too late. And it's a history of what could not be recovered once the warming stopped.

2046-2055: The Great Climate Turn

The political transformation that eventually halted global warming began with the Great Hunger of 2045–46.

As every schoolchild knows, in 2044 an exceptionally powerful El Niño intensified drought and heatwaves in all of the world's major food-producing regions. Harvest failures led to food shortages, and commodity prices surged to new highs. Malnutrition, famine, and ultimately starvation on an unprecedented scale combined with outbreaks of epidemic disease.

By 2046, an estimated 60 million people had died.

Climate change hadn't caused the famine by itself. Soil degradation, depleted aquifers, fragile trade networks, simmering conflicts, and years of underinvestment all played a role. But climate change *had* clearly amplified the effects of a powerful El Niño that, in turn, synchronized regional droughts and heatwaves, turning agricultural vulnerabilities into a worldwide catastrophe.

In the wake of the Great Hunger, public outrage in many countries transformed decarbonization into an emergency program for food security, political stability, and human survival.

The transition away from fossil fuels did not depend on a single miraculous technology. Solar and wind power expanded fastest because they were already relatively cheap and could be installed quickly. Long-distance transmission lines carried electricity from sunny or windy regions to places where demand was highest. Batteries, pumped-storage hydroelectricity, thermal storage, and increasingly accurate weather forecasts – improved using ever more capable AI systems – helped grid operators match fluctuating supplies of renewable power with changing demand.

Existing nuclear plants were kept open beyond their originally planned retirement dates, and several countries built new large reactors. Small modular reactors – factory-produced nuclear units designed to be installed in stages – also played a narrow but still important role in the energy transition. They supplied industrial centers, isolated electricity grids, and countries that wanted reliable low-carbon power but could not afford the enormous initial cost of conventional nuclear plants.

Commercial fusion arrived late and remained expensive. Today, it still provides only a modest share of global electricity rather than serving as the foundation of the energy economy, but that share is poised to grow.

Fossil fuels disappeared first from electricity and ordinary road transport. Electric cars, buses, and railways were already common before the famine. After 2046, strict efficiency rules, carbon prices, and outright bans finished off the internal combustion engine. Fossil fuels were harder to eliminate from shipping, but new vessels increasingly harnessed the wind – just like sailing ships of old.

Long-distance aviation, steelmaking, and cement production proved hardest to decarbonize. Still, airlines gradually shifted toward low-carbon and synthetic fuels; steelmakers adopted electric furnaces and hydrogen; and cement producers relied on cleaner heat, alternative materials, and carbon capture.

Agriculture changed just as dramatically, but not in the way some had imagined. True, vertical farms and climate-controlled greenhouses became important sources of vegetables, seedlings, and high-value crops near wealthy cities. But they could never replace open fields that produced most of the world's rice, wheat, and maize.

Governments funded research into crops better able to survive heat and drought, as well as forecasts that gave farmers more warning of dangerous weather. They also helped farmers conserve water, rebuild depleted soils, and plant trees around fields and pastures to retain moisture and prevent erosion.

New rules reduced methane emissions from oil and gas production, livestock, and rice farming. Some required farmers to use less nitrogen fertilizer, and apply it more carefully. In many wealthy countries, meat consumption declined as alternative sources of protein became cheaper, tastier, and more widely available.

The changes were uneven. Wealthy states could subsidize new infrastructure and compensate workers in declining industries. Poorer countries, by contrast, often faced high borrowing costs, weak electrical grids, and growing populations.

The United Nations had long since ceased to be effective. But in 2049, the governments of China, the European Union, and the United States launched the Climate Recovery Compact, a multilateral agreement that tied debt relief and development finance to decarbonization and adaptation efforts in developing nations. The Compact was paternalistic, often corrupt, and periodically weakened by the outcome of elections. Still, it seems to have accelerated the energy transition across South and Southeast Asia, Africa, and Eastern Europe.

By the early 2060s, global carbon dioxide emissions were falling steeply. Emissions of *all* greenhouse gases, including methane and nitrous oxide, had clearly plateaued. Global warming seemed like a problem that was well on the way to being fixed.

2055-2085: Warming After the Turning Point

One of the hardest lessons of the past century was that falling emissions did not immediately mean falling temperatures.

Greenhouse gases accumulate in the atmosphere – especially carbon dioxide, which can take centuries or even millennia to be absorbed by oceans, soils, and rocks. As long as humanity released more carbon dioxide than Earth could absorb, its concentration in the atmosphere continued to rise. But power stations and vehicles that used fossil fuels couldn't be replaced overnight.

So, the world kept warming long after the political turning point of 2046. And worse, the sensitivity of Earth's climate to greenhouse gases turned out to be on the high range of what climate models had simulated.

By the 2050s, heatwaves of previously unimaginable duration and intensity were common across the Middle East, South Asia, North Africa, and the Sahel. The Persian Gulf states protected many of their citizens with reliable electricity, air conditioning, desalination, and imported food. But even there, outdoor work was dangerous for much of the summer, and migrant workers received less protection than citizens.

In poorer countries, heatwaves caused blackouts, crop failures, and mass mortality. Heat did not kill only by pushing the human body beyond its limits. It also worsened heart, kidney, and respiratory disease; reduced labor productivity; spoiled food and medicine; and made hospitals more likely to fail when they were needed most.

Water shortages sharpened political conflicts, even when they didn't directly cause them. In Mali, Burkina Faso, Syria, and parts of the Horn of Africa, drought and erratic rainfall intensified competition over wells, grazing land, and irrigation. Armed groups exploited displacement and resentment.

It was now a well-worn cliché among military officers that climate change was a threat multiplier. Extreme weather created new ways for old resentments to spark conflict, it made it harder for conflict to end once it began, and it complicated military operations.

By the late 2050s, the Atlantic Meridional Overturning Circulation, or AMOC, was clearly weakening as the North Atlantic warmed and received more freshwater from melting ice. This vast system of currents carries heat northward through the Atlantic. Its slowdown partly offset warming around the northern North Atlantic, especially in winter, and altered rainfall, storms, marine ecosystems, and regional sea levels.

Most of Europe still became warmer overall. Yet a handful of severe winters, including those of 2059 and 2064, exposed millions of elderly and low-income residents to frigid temperatures in countries where decarbonization efforts had increased winter energy prices. Tens of thousands died from hypothermia, heart attacks, strokes, respiratory infections, accidents, and disruptions to electricity and medical care that could all be tied, at least indirectly, to frigid winter weather.

One of the paradoxes of the period was that a warming world could still produce deadly cold spells – and household income often determined who survived.

Coastal societies faced a slower emergency. Global mean sea levels were about 20 centimeters higher by the middle of the century than they had been 50 years earlier. Even this relatively modest rise allowed storm surges and high tides to reach farther inland.

Today, the global average is about 80 centimeters above late 20th-century levels – and with extreme, in some cases unanticipated, regional differences.

Low-lying island states didn't disappear overnight. They slipped under the waves, gradually, one shoreline, one neighborhood at a time. A stretch of coastal dunes might be lost at high tide. Then, a couple years later, a road – and then a cemetery. A row of beachfront cottages might be swamped in a storm, or a clutch of one-story homes in a floodplain.

At first, the water receded. But each flood began from a higher level. Eventually, some places never fully dried out. Meanwhile, saltwater seeped into underground aquifers, spread through soil, and killed plants and trees long before they disappeared beneath the waves.

As insurers withdrew and rebuilding became increasingly unaffordable, more families and more businesses had little choice but to leave. Eventually, governments left too.

A 2023 migration arrangement between Australia and Tuvalu, an island nation in the South Pacific, became a model for later agreements. Under the Falepili Union Treaty, up to 280 Tuvaluans each year (out of a population of less than 10,000) could become permanent residents of Australia. There they could live, work, and study while continuing to travel back to their homeland.

By the 2060s, a succession of island governments signed similar treaties with countries around the world. Some island populations stayed together after they moved to new countries, forming communities that received special recognition from the governments of those countries – akin to that given to Indigenous nations in Australia, Canada, or the United States. When some islands became truly unlivable, their governments finally moved with their populations, and most claimed partial authority over the transplanted communities. It was almost as if island populations, cultures, and states had moved across the world, to durable land.

But the sovereignty of island states now depended on the largesse of governments in the countries to which they had removed themselves. Governments of these countries provided islanders with more or less sovereignty, or changed sovereignty agreements from one election to another. Disputes over sovereignty stoked violent resistance in some transplanted communities. Yet there was no getting around a harsh reality: island nations were now only a part of much larger polities.

The population of Tuvalu's neighbor, the Republic of Kiribati, therefore charted a different path. Rather than moving under one formal agreement, people from Kiribati left in diverse ways. Some joined government-supported relocation schemes. Some took jobs overseas. Others moved to live with relatives who had already settled abroad.

In the end, an island nation dissolved, and its government disbanded. But people have left on their own terms, without the paternalistic assistance of a colonial state.

Meanwhile, tropical cyclones were changing. The total number of storms didn't rise everywhere. Instead, the strongest storms became ever more intense, while rainfall rates increased. More and more storms also intensified with explosive speed, and higher seas amplified storm surges.

In 2055, 2058, and 2062 – across the Philippines, China, and Mexico – tropical cyclones repeatedly made landfall with sustained winds that exceeded 330 kilometers per hour. The unprecedented intensity of the storms, combined with the rapid growth of coastal populations and economies, meant that each cyclone killed thousands, and each inflicted over $750 billion in damage (in 2060 USD).

In the United States, the National Hurricane Center added a new category – 6 – to the Saffir–Simpson Hurricane Wind Scale. Meteorological agencies in several other countries soon adopted equivalent categories.

Clearly, governments had not cut greenhouse gas emissions quickly enough to prevent the emergence of a new, much more dangerous climate.

2046-2091: Jakarta's Long Retreat

Jakarta wasn't in the usual path of even the new, supercharged typhoons. But it *was* exceptionally vulnerable to flooding – because as sea levels rose, the city itself was sinking.

Decades of unsustainable groundwater pumping had drained and squeezed together the soft sediments beneath northern Jakarta. The ground sank in response, but this *subsidence* varied greatly from place to place. Early 21st century studies measured typical rates of subsidence in northern Jakarta at several centimeters per year. But in some neighborhoods, the land was sinking at around 20 centimeters per year – more than the sea could rise in a decade.

Already in 2022, the government started building a new capital – Nusantara – to move institutions out of an overcrowded, sinking metropolitan area. Yet relocating the capital wasn't the same as moving one of the world's largest urban populations, let alone the infrastructure – from businesses to ports to roads – that made Jakarta Indonesia's economic center. In fact, millions continued to migrate to Jakarta from a countryside increasingly wracked by floods and droughts.

Adaptation bought time. New reservoirs and piped-water systems reduced groundwater extraction in some districts. Engineers built sea walls, dredged rivers, improved pumps, and elevated thousands of homes. Governments, local communities, and non-governmental organizations restored mangroves, natural defenses against the sea that trap sediment and reduce erosion.

Yet protection tended to follow wealth and political influence, more than need. Business districts, ports, and affluent neighborhoods received the strongest defenses. By contrast, some of the city's poorest neighborhoods, alongside rivers and canals, were demolished in the name of flood control. Residents were moved to distant housing with poor transportation networks and few nearby jobs.

In the 2070s, Indonesian authorities adopted a policy they called *managed retreat*, though few experienced it as orderly or voluntary. Jakarta's northern neighborhoods, outside the main defenses against the sea, were converted into retention basins, wetlands, aquaculture zones, or open water. Millions complained that compensation rarely matched the value of lost homes and livelihoods. And some families moved repeatedly as supposedly safe districts flooded, one after the other.

Then, in 2091, an exceptionally strong La Niña cooled the central and eastern tropical Pacific, further concentrating warm waters in the western Pacific and strengthening the Asian–Australian summer monsoon. Months of unusually heavy rainfall swelled rivers until an unprecedented downpour coincided with a spring tide.

Several pumping stations lost power, and sections of an aging coastal barrier failed. Floodwaters surged into Jakarta, mixing with sewage and industrial waste. The immediate death toll was lower than it would have been earlier in the century, both because forecasts had improved, and because governments and individual families were more prepared for evacuation. But thousands still drowned, and a humanitarian crisis lasted for weeks. Diarrheal disease spread through crowded shelters, hospitals ran short of clean water, and food prices soared. These indirect consequences of the flood might have killed over 100,000 people.

My family's home was on the second floor of a sprawling apartment complex. It was far inland, in a district officials had classified as defensible. We thought we were safe.

But just after sunset on March 3rd, 2091, we learned that water had surged into our neighborhood. Our parents didn't know what to do at first. People were crowding the streets. Everyone was panicking. I still remember the shouting of the grown-ups, the crying of the children – and the look in my father's eyes.

After a few hours, we packed our bags. Just a few; my mother didn't believe that the flood could reach our apartment. We pushed our way through the crowd, to the car, and inched out of our neighborhood in heavy traffic.

Later, we learned that the water had peaked above the third floor. We lost everything we hadn't packed. But because my mother worked for the civil service, we had housing rights in Nusantara. We could rebuild.

Many of our neighbors weren't so lucky. Some moved into camps beyond the new capital. Others stayed with relatives or returned to flooded neighborhoods as soon as the water receded.

And many had drowned.

Jakarta was never wholly abandoned. Its southern and central districts are still home to millions. Fortified corridors connect the port to the national economy. But much of the northern city is now a wasteland of crumbled buildings, polluted wetlands, and submerged memories.

Tour companies organize boat trips that take foreigners among the ruins. Business is good. The national government promotes disaster tourism. Officials say it shows foreigners that Indonesia adapted to the rising waters.

But that word – *adaptation* – doesn't capture what it meant to lose a home. A place we thought would last forever.

2050-2080: The Living World Contracts

The breadbasket failure changed more than human politics. Emergency efforts to expand farmland, resettle displaced people, and secure timber and minerals increased pressure on ecosystems. Many of these ecosystems were already breaking down, owing not only to the changing climate, but also to pollution, pesticide use, invasive species, and habitat loss.

Overall, most ecosystems might have been able to adapt to warming temperatures. But climate change only exacerbated the damage caused by the way governments and corporations had used up the world's environment. Many ecosystems collapsed because they were already near their breaking points.

The Amazon rainforest provided the clearest example.

Midway through the 21st century, the rainforest still covered much of the Amazon basin, which in turn stretched across nearly half of South America. The forest created much of the rain that allowed its own plants to grow. Its trees drained water from the soil, then released it through their leaves, allowing moisture to be recycled across the Amazon basin.

Deforestation, repeated drought, and fire threatened this cycle. For decades, scientists had warned that parts of the forest could cross thresholds beyond which drying and tree loss reinforced one another. Some South American governments heeded those warnings, taking steps to curb deforestation and imposing more ambitious decarbonization targets. But others reversed those policies.

Then, in the 2060s, the Amazon began to break down. The forest didn't wither all at once, or in a single year. Instead, the southern and eastern Amazon slowly transitioned into a mosaic of fire-prone, degraded woodland, open savannah, and – increasingly – maize and wheat fields.

In the north and west, wetter regions survived, especially where Indigenous territories and protected areas limited clearing. But countless species, many still unknown to science, either lost much of their population or went extinct. The Amazon basin as a whole became a net producer, rather than an absorber, of carbon dioxide, slowing efforts to reduce atmospheric greenhouse gas concentrations.

In a way, the Amazon limped on like Jakarta. If you were in the right spot, it seemed like little had changed. But overall, it was a shadow of its former self.

Boreal forests changed in a similarly uneven way. Trees and shrubs spread north into warming tundra. But every summer – across Alaska, Canada, Scandinavia, and Siberia – heatwaves, droughts, invasive insects, and enormous fires devastated forests along their southern margins.

Smoke became a recurring public-health emergency across North America, Europe, and Asia. In some years, burned forests and thawing soils released so much carbon that northern ecosystems also became a source of greenhouse gases, rather than a sink.

Many ecological disruptions involved timing. Plants flowered earlier than before, but some insects emerged with seasonal changes in lighting that had increasingly little relation to temperature. Migratory birds, following instinct, arrived after peak food supplies had passed. These mismatches did not affect every species in the same way, but they destabilized relationships between plants and animals that had developed over thousands or even millions of years.

Wild pollinator populations crashed in many heavily farmed regions. Farmers responded with managed bee colonies, robotic pollination, and, for a few expensive crops, hand pollination. Those substitutes kept markets supplied, but they increased food prices – and they didn't recreate ecosystems that had once provided pollination for free.

Warm-water coral reefs suffered the most visible collapse. Already in the early 21st century, marine heatwaves bleached reefs before they could recover. Meanwhile, carbon dioxide from the atmosphere entered seawater, making it more acidic. That in turn made it increasingly difficult for corals to grow their skeletons, and other invertebrates to grow their shells.

By the 2060s, the Great Barrier Reef no longer functioned as a single, connected ecosystem. Several scattered, carefully maintained reefs survived off Northeastern Australia, but the extraordinary biodiversity that had characterized the region was gone for good.

Reefs around the world experienced similar breakdowns, albeit on a smaller scale. Some algae, sponges, fish, and some heat-tolerant corals clung to life. But by the late 2060s, the beautiful, three-dimensional reef structures that had sheltered countless species, protected coasts, and supported fisheries had largely disappeared.

A century ago, prominent scientists and journalists announced that the sixth mass extinction in Earth's history had already begun. At that time, some biologists protested that species losses hadn't reached the scale that defines a mass extinction. Others stressed that extinction rates were difficult to measure.

Today, AI systems confirm that those rates are rising at alarming speeds.

Warming near 3 °C has pushed already threatened species beyond recovery. And it has driven previously thriving populations to the brink of collapse.

Stabilizing temperature prevented still greater losses. But it did not bring the vanished species back.

2060-2090: Disease in a Rearranged World

Nearly a century ago, biologists determined that warming had started to alter the geography of disease.

By the 2060s, the world was clearly becoming a less healthy place. Warmer temperatures allowed mosquitoes and ticks to survive at higher elevations and latitudes. Floods created mosquito breeding sites and disrupted sanitation. Deforestation and agricultural expansion brought people, livestock, and wildlife into new forms of contact, creating opportunities for pathogens – the microscopic causes of disease – to spread to new hosts.

None of this meant that climate change automatically produced pandemics. A pathogen still had to cross into people, spread efficiently, and evade public-health defenses. But environmental disruption created more opportunities for those steps to occur.

Four outbreaks came to define the second half of the century. In 2062, a mosquito-borne virus emerged in a heavily disturbed forest region of Central Africa and spread through parts of the Sahel. Vaccines eventually contained it, but only after it killed an estimated 750,000 people, most of them in places with weak health systems.

Beginning in 2073, a new coronavirus, eventually named SARS-CoV-3, caused a worldwide respiratory pandemic. Its estimated death toll, depending on how indirect deaths were counted, might have approached 200 million. Like COVID-19, it never disappeared completely; descendants of the virus still circulate as seasonal infections.

As the world struggled to recover, a new virus, engineered by an AI, escaped containment from an American Biosafety Level 4 (BSL-4) laboratory. The virus was not nearly as contagious as other engineered pathogens stored at BSL-4 facilities. But it was extraordinarily deadly, and it sparked widespread panic.

The fourth crisis was less dramatic but more persistent. Beginning in the 2080s, waves of drug-resistant tuberculosis swept through camps and relocation districts that now housed hundreds of millions of climate refugees. It is still difficult to estimate how many died. Some AI systems suggest that the death toll was ultimately greater than that of the CoV-3 pandemic.

Governments responded to these disasters by building global pathogen-surveillance systems that rapidly sequenced the genomes of emerging viruses and bacteria. They constructed AI-enhanced vaccine factories, and imposed new indoor-air standards for schools and workplaces. Cheap diagnostic devices allowed people to detect infections at home, and helped health officials stop outbreaks before hospitals filled.

Some groups rejected new policies and technologies. Pathogens engineered with AI continued to pose terrifying threats to global health. But for the time being, new measures ensured that, outside of refugee camps, most disease outbreaks remained local.

Is that a success? As usual, it depends on who and where you are.

2070-2100: Unequal Stabilization

The clearest pattern in the history of global warming is that responsibility for risk and exposure to risk were rarely, if ever, shared by the same people.

In the nineteenth century, Great Britain released more carbon dioxide than any other state. In the 20^{th} century, the United States became the largest cumulative emitter. In the 21^{st} century, China took its place. Wealthy fossil-fuel exporters in the Middle East also shared responsibility for a large share of global emissions.

Many people in these countries benefited, directly or indirectly, from the industries that changed the climate. Wealth created by those industries also helped give governments the money, technology, and administrative capacity to make their populations more resilient in the face of climate change.

New York, Shanghai, and Singapore, for example, expanded seawalls, pumps, and floodable parks. Gulf cities built desalination plants and cooled transit systems. Wealthy households everywhere bought backup batteries, air filtration, insurance, and homes in safer locations.

Granted, there was no way to be perfectly safe in a warming world. But money reduced mortality and accelerated recovery.

Poor countries and poor neighborhoods faced the same hazards with far fewer defenses. Insurance withdrew from exposed coasts and fire-prone regions. Outdoor workers lost income during heat emergencies. Residents of informal settlements were excluded from official compensation, because they lacked legal title to their homes.

Climate adaptation was often described as a technical challenge, an engineering problem. But the success of adaptation depended less on the infrastructure societies built than on decisions about who would be protected, who would pay, and whose losses would count.

In the 2060s, the prospect of massive migration from the Global South to the Global North finally led to decisive expansion of international climate finance. The Climate Recovery Compact provided a foundation for developed nations to expand the Loss and Damage Fund, which had been created decades earlier to help vulnerable countries cope with losses they could no longer prevent through adaptation.

New grants financed sea walls, drought relief, the relocation of displaced communities, and the rebuilding of electrical grids. Receiving countries used the prospect of migration to acquire some power over how funds were spent. Even so, the sums remained modest compared to the value of lost land, cultures, ecosystems, and lives.

Money could help a family move; it could not recreate a place that was gone forever.

The camps around Nusantara embody this complex history. The new capital offered jobs, schools, and safer ground. But housing construction never matched migration. Some neighborhoods that began as emergency settlements in 2091 now have paved roads and elected councils. Others still lack sewers and secure land rights.

My family remembers our move as an escape. Many of our former neighbors remember the same event as an expulsion. Both memories are true.

2080-2100: Overshoot and the End of Warming

Climate scientists say we are experiencing an *overshoot*: a temporary rise in global temperatures above the 2 °C limit of warming that governments had long promised to avoid.

The overshoot began in 2046. It peaked in the late 2080s, when global temperatures reached 2.95 °C above their average in the late 19th century. And it's ending, because Earth's temperature has finally started to fall.

Today, Earth's temperature is still around 2.85 °C above the late 19th-century average. It's projected to decline further during the 22nd century – if carbon dioxide removal continues, and if the bulk of the world's forests survive.

The word “overshoot” can sound reassuring. It’s as though the world’s temperature briefly crossed a dangerous line, then returned to safety.

That isn’t how it felt. Even when temperatures began to fall, every year brought heatwaves, droughts, and floods that killed tens of thousands of people.

Many consequences of warming can’t just reverse themselves now that temperatures are declining. Extinct species are gone for good. Glaciers crossed thresholds that commit them to centuries of additional melting. Coral ecosystems that took millennia to build can’t be recreated.

Climatologists had long warned that overshoot increased the odds of pushing parts of Earth’s climate system across tipping thresholds. But tipping points were never tripwires – and luckily, many failed to materialize.

The AMOC weakened, but it didn’t collapse. The Amazon is degraded, but it hasn’t disappeared. The great ice sheets lost mass, but there was no sudden collapse into the ocean, as some scientists had feared in West Antarctica.

In a sense, humanity was fortunate.

The slight decline in temperature also didn’t depend on geoengineering: deliberate efforts to cool Earth’s climate. After 2046, governments repeatedly debated injecting reflective particles into the stratosphere. Those debates intensified with the disasters of the 2050s and 2060s.

But *stratospheric aerosol injection,* as it’s called, never went anywhere.

Governments simply couldn’t agree on which state or entity would be responsible for releasing the particles. They couldn’t decide how to attribute extreme weather to the intentional modification of the climate, rather than global warming or natural climatic variability. They couldn’t determine how to compensate states for this weather, what the ideal temperature of the Earth should be, or how to protect geoengineering efforts during wars between states.

So, the world relied on decarbonization and carbon dioxide removal.

Many lamented that this approach could only have kept warming below dangerous levels if governments had seriously committed to it earlier: in the twentieth century, or even the early 21st century. By the *middle* of the 21st century, decarbonization alone couldn’t prevent warming from peaking at just under 3 °C, relative to the world’s average temperature in the late 19th century.

But unlike geoengineering, decarbonization addressed the physical *cause* of warming. It didn’t just mask the *effects* of that cause. That made it a true solution, not a precarious quick fix.

Reaching net zero emissions didn’t end climate policy, because net zero requires constant work. Aging infrastructure still has to be replaced. Forests still need to be preserved, and underground carbon storage reservoirs require constant monitoring.

Emerging political movements continue to blame all social ills on decarbonization. Some call for a return to the better days of the 20th century. Populist movements seek to restore the greatness of the world's former oil, gas, and coal producers.

But the world's energy system seems to have moved on for good. Efforts to revive the fossil fuel industry appear doomed to failure.

2100: Success, But at What Price?

In a narrow but important sense, we can look back on the 21st century with pride.

Around the world, many governments, corporations, and individuals responded constructively to the Great Hunger of 2046. Within decades, they had all but completed a total restructuring of energy, transportation, industrial, and agricultural systems. Food systems recovered, global populations continued to inch upwards – and the climate stopped warming.

The Earth remains broadly habitable, and home to a functioning, global civilization.

But *habitable* is such a low standard. Keeping Earth habitable doesn't mean that every place remained livable, every culture survived, or every community received a fair chance.

Today's world is a diminished place. My generation inherited an Earth with fewer species, smaller ice sheets, higher seas, harsher heat, and cities divided between protected enclaves and abandoned districts.

Jakarta captures the contradiction.

The metropolis survives, and Indonesia's economy has grown with the clean-energy transition. Yet my childhood neighborhood lies inside a tidal basin. My parents' apartment edges above the waves only at low tide.

People who lived through the Great Hunger liked to say that despair was a luxury the world could no longer afford. They were right. Because they acted, my generation has a future.

But action came only after decades of delay made tragedy unavoidable.

We know who to blame for all that's been lost. They're the politicians, business leaders, and pundits who prioritized wealth, fame, or power over humanity's future. They knew that the world was warming. They also knew that the worst consequences would wait until long after they died.

In their day, I suppose they were remembered fondly. They achieved admirable wealth and power. They supported institutions and political movements. They were benefactors and family men.

But we are their victims. We, who were not yet born. Our lives were a distant prospect. A meaningless abstraction.

Now, we control their legacy. And we will ensure that their selfishness – their shortsightedness, their cruelty – is never forgotten.

The Four-Degree World, 2046-2100

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Introduction: A World Transformed

I grew up in Mendoza, a green city in the middle of a desert.

That green wasn't natural. Mendoza never received enough rain to support its vineyards, orchards, parks, and hundreds of thousands of roadside trees. It was an artificial oasis – one that took centuries to build.

The Indigenous Huarpes dug irrigation channels before the Spanish conquest. Settlers extended them into a sprawling network of canals and *acequias*: narrow channels running beside many streets. The acequias rerouted water from the Andes, transforming an unassuming patch of arid land into a haven for plants, animals – and people.

My grandparents tell me that, when they were children, this hydraulic system seemed almost miraculous.

Snow piled up high in the Andes during winter, then melted through spring and summer. The Mendoza River carried that water through the Potrerillos reservoir, into canals serving homes, farms, industries, and the urban forest. Plane trees and poplars entangled their branches above the streets, their shade cooling even the hottest summer days.

But by the time I was born, the miracle must have seemed like a distant memory.

Rapid warming meant that more winter precipitation had started to fall as rain, not snow. The snowline had retreated into the Andes, while the spring melt arrived earlier. Glaciers that once released water even during the driest years had lost much of their ice.

The Mendoza still flowed, but its seasonal rhythm had changed. More snowmelt arrived early in spring, leaving less water for long, hot summers, when farms and cities needed it most. Reservoirs held part of the early melt, but the water evaporated in summer heatwaves until little was left. Each drought forced the same argument: should remaining water go to households, vineyards, factories, wetlands – or the trees that made the city bearable?

Today, Earth is, on average, about 4 °C warmer than it was in the late 19th century.

Some still struggle with that number. It just can't capture just how much Earth has changed. It hides how continents have warmed much more than water, how the far north has warmed more than lower latitudes – or how days, weeks, and entire seasons can reach temperatures unimaginable before our century.

Earth is a fundamentally different planet than the one my grandparents knew. A planet that is no longer a safe home for humanity.

This outcome was not inevitable.

Our world emerged from choices made by powerful governments, corporations, and elites. Because of their decisions, fossil-fueled power plants and cars accumulated faster than clean energy alternatives could replace them. Forests and soils were left to deteriorate.

Repeated crises fractured multilateral institutions and the very spirit of international cooperation. Each disaster led governments to hoard their own resources, rather than cooperate to confront a common threat.

The century has not ended in human extinction. Billions of people remain alive. Many cities still function. But societies have become poorer, more coercive, and more divided. Billions have died in catastrophes that AI systems link, directly or indirectly, to climate change. Hundreds of millions more are displaced.

Governments have normalized emergency powers, rationing, fortified borders, and the forced abandonment of places judged too expensive to protect. In many of the world's biggest cities, outdoor life disappears for much of the summer. People wander through vast, underground corridors between sealed buildings, cooled by air conditioning systems hooked to redundant power grids.

This is the history of how global warming diminished our planet and crippled our civilization.

Not because no one understood the danger. Because those powerful enough to safeguard our future cared more about enriching themselves in their present.

2044-2053: The Great Hunger Dooms Climate Action

The multiple breadbasket failure of 2044-46 was a turning point. But not as climate activists had hoped.

As a severe El Niño amplified the effects of global warming, extreme heat, drought, and flooding simultaneously struck the world's major food-producing regions. Decades of unsustainable groundwater exploitation and, in some places, disruptions caused by war meant that the consequences were even more severe than they might have been.

A century of globalization made the global food system efficient but brittle. Internationally traded wheat, maize, rice, and soy harvests came from a handful of places where soils, climates, farms, transportation networks, and government subsidies combined to make it easy to grow and move food. Grain reserves were kept low to reduce costs, and governments assumed that markets would always move food from surplus to shortage.

But during the Great Hunger, many of the world's largest food exporters restricted sales at the same time. Governments that could pay bought what remained; governments that couldn't pay were powerless as their citizens went hungry.

Argentina was among the hardest hit countries. Farm products and food accounted for more than half of its export income. But from 2044 to 2045, record heat gave way to weeks of torrential rain, as hot water across the tropical Pacific directed more and more moisture toward southeastern South America.

Floods and waterlogged fields cut soy and maize production across the Pampas, and damaged the wheat harvest. The swollen Paraná disrupted navigation and severed road and rail links to grain terminals around Rosario, delaying exports for weeks.

Revenues from exports collapsed just as the price of bread, cooking oil, animal feed, and imported machinery rose. It was a perfect storm. Inflation accelerated, rural employment slumped, and governments lurched between export taxes, price controls, and emergency subsidies.

Each measure protected one group, while shifting losses to another.

The aftermath of the crisis also exposed a glaring contradiction in the clean-energy economy. It began when El Niño conditions gave way to a strong La Niña event that cooled the waters of the tropical Pacific, even as the world warmed. Colder water evaporates less easily and heats the air above it less strongly. Atmospheric circulation changed, bringing less rain to parts of South America.

Now, lithium extracted from salt flats in northwestern Argentina was essential to the batteries that powered the green economy. But this extraction was altering water flows in some of the driest landscapes on Earth. Mining companies pumped briny, mineral-rich water from beneath salt flats. They used precious freshwater to separate lithium from other salts, clean equipment, and supply workers' camps.

Indigenous leaders warned that surface pools, wetlands, grazing lands, and freshwater aquifers were connected in ways monitoring programs couldn't see. Locals complained that foreign companies were draining water from one of Argentina's poorest regions to fuel the insatiable energy demands of the world's richest countries and companies. Corporate and government officials responded by insisting that lithium extraction permitted a global transition away from fossil fuels – which, in a roundabout way, benefited everyone in Argentina.

Amid severe droughts, protests around three of Argentina's most important lithium mines turned deadly in 2048 and 2049. Worldwide media attention deepened distrust of renewable energy and the green economy not just in Argentina, but around the world.

By then, renewable electricity had expanded for decades. Solar panels, wind turbines, batteries, heat pumps, and electric vehicles prevented some warming than would otherwise have occurred. But there hadn't been an energy transition away from fossil fuels, but rather an energy *addition*. Renewables met soaring electricity demand from data centers and continued economic development across Asia and Africa; they didn't replace the energy generated by fossil fuels.

Oil and gas still powered a large share of energy production, not to mention most aviation and shipping. Fossil fuels supplied petrochemicals and high-temperature industrial heat, and remained essential to farming. Every year, tens of billions of tons of carbon dioxide and other greenhouse gases continued to pollute the atmosphere.

The 2046 famine was called a betrayal by environmental activists because it wouldn't have happened had governments acted to stop global warming. But others called it a betrayal because it revealed avoidable shortcomings in the world's food system that had nothing to do with climate. Many argued that the famine had little relation to climate – El Niño, after all, had always occurred – and polling revealed that a plurality of the public adopted this view in many of the world's largest economies.

Ironically, the Great Hunger fueled a backlash against climate action. To prevent another subsistence crisis, governments subsidized diesel for tractors and trucks, reopened coal plants to lower electricity prices, and signed new contracts for oil and liquefied natural gas.

Then, in 2048, a crisis in Nigeria – a country where large majorities still believed that the world was warming and that action was urgently needed – doomed global efforts to cut emissions.

After the Great Hunger, Nigeria's government responded to popular pressure by ending fuel subsidies and canceling new oil and gas projects. Petrol prices soared, making food and transport still more expensive, and leaving many households and businesses unable to run the generators they relied on during power cuts. There wasn't enough renewable electricity, public transit, or support for displaced workers, so the country slid into a severe recession.

High food prices roiled communities that had been traumatized by the Great Hunger. Mass protests quickly metastasized into a bloody uprising that, after weeks of violence, culminated in a military coup.

Across the Global South, officials used the crisis to argue that calls for decarbonization amounted to a new form of colonialism – one that could let wealthy countries slow the growth of potential competitors and control their governments. And in the Global North, politicians argued that decarbonization would be pointless if it didn't involve rapidly growing economies in Africa, South America, and South Asia. Many governments abandoned longstanding pledges to limit greenhouse gas emissions.

The collapse of efforts to cut those emissions led some governments to approve *geoengineering* experiments. Geoengineering refers to an intentional intervention in Earth's climate system that counteracts global warming.

Sweden and Japan greenlit three large-scale demonstrations that used high-altitude drones to release sulfur compounds into the stratosphere. As climate models had predicted, these compounds formed tiny reflective particles, known as *aerosols*, that cooled the lower atmosphere by scattering incoming sunlight.

But the tests needed to create a lot of aerosols to generate measurable cooling, and their scale helped spark widespread popular opposition. The Great Hunger had led to a collapse in public trust in government, even in wealthy countries where it had led to severe inflation, rather than food shortages. Few now believed that governments could successfully manage a global climate modification program, and popular conspiracy theories even blamed secret geoengineering experiments for the famine.

In a sense, the public was right. Tentative efforts by a handful of countries to create a UN resolution on geoengineering soon revealed that there were simply too many questions that governments couldn't answer. For example: who would control the aircraft and decide the target temperature? How would governments determine whether a drought or flood had been influenced by the intervention? Who – or what – would compensate countries harmed by changes they had not approved?

It surprised no one that the same international order that had failed to cut greenhouse gas emissions could not decide how to dim the Sun.

2053-2062: The Marine Food Crisis

The next great food shock began at sea.

Historians have described 2053 as the year the world's fisheries collapsed. The phrase is memorable, though perhaps misleading. Fish didn’t disappear everywhere at once. Instead, warming, overfishing, acidification, oxygen loss, habitat destruction, and political conflict all combined to produce a rolling series of regional failures that the global market could no longer absorb.

Off Peru, a poor anchovy season in 2053, connected to warming supercharged by another strong El Niño, drove up the price of fishmeal used to feed farmed fish. Meanwhile, in the western Pacific, disputes over fishing fees led island governments to bar foreign tuna fleets from unloading at ports such as Majuro and Tarawa. Off northern Greece, marine heatwaves killed millions of mussels across the Thermaic Gulf.

Increasingly, the consequences of regional shortfalls in marine harvests reinforced one another.

For decades, the oceans had absorbed most of the excess heat trapped by greenhouse gases. Marine heatwaves had become longer, more intense, and more extensive, pushing many species toward the poles or into deeper water. Tropical countries generally lost potential catch while some high-latitude fisheries temporarily gained unfamiliar species.

As warming waters drove valuable fish populations from one country’s waters into another’s, fishing agreements became outdated. Governments increasingly disputed who could catch the fish, and how many they could catch. Illegal fishing expanded as governments struggled to patrol larger and more contested waters.

Ocean acidification added still more pressure to fish stocks. When carbon dioxide dissolves in seawater, it changes the water's chemistry and reduces the carbonate ions used by corals, oysters, clams, sea snails, and some plankton to build shells and skeletons.

Warm-water coral reefs suffered most visibly.

Repeated marine heat waves caused bleaching by forcing corals to expel the algae that supplied most of their energy. When the heat persisted, or returned too frequently, colonies died faster than reefs could recover. Ocean acidification then made it harder for surviving corals to build their skeletons, while increasingly powerful storms shattered reef structures that had taken centuries to form.

By the 2060s, most tropical reefs no longer functioned as the complex three-dimensional ecosystems that had sheltered juvenile fish, weakened waves, supported tourism, and sustained coastal cultures. Only small corals clung to life in cooler refuges, deeper water, and places with strong currents.

Overall, the world's marine catch had now fallen by roughly a third from early-century levels. That average concealed even more severe losses in tropical and enclosed seas.

In many coastal communities, fishing provided not only essential nutrients and meaningful work, but also a sense of continuity between generations. Unique fishing cultures now began to unravel, even as malnutrition swept across poor communities that had depended on fish for protein.

Wealthier consumers shifted toward expensive aquaculture, or imports from the remaining productive waters. Once again, those most responsible for the crisis suffered least.

2058-2075: Disappearing Ice, Rising Seas

In 2058, satellites began to measure an abrupt acceleration in ice loss from West Antarctica.

Several of the continent's vast glaciers rested on the ocean floor. As the edges of these glaciers retreated, they reached places where the bottom of the ocean sloped downwards, opening a space for warming seawater to penetrate beneath the glaciers. The water began to melt the glaciers from below, even as warm air temperatures melted them from above. Dark water pooled on the surface of the glaciers, absorbing more sunlight than the bright ice and intensifying the melt.

Warmed from above and below, Antarctic glaciers retreated with accelerating speed. And because the process had become self-sustaining, it was irreversible on human timescales.

Sea-level rise accelerated through the second half of the century. Thermal expansion – the tendency of seawater to occupy more volume as it warms – accounted for part of the rise. But an increasing share came from meltwater flowing off mountain glaciers, and icebergs calving from the ice sheets of Greenland and Antarctica.

By 2100, average global sea levels were some five feet higher than they had been a century earlier. In many places – where land was sinking or rising; where currents were shifting; or where the gravitational pull of shrinking ice sheets was changing – the sea was lower, or even higher, than the global average.

Some places vanished quickly, in storms that shattered defenses against the sea and established a new coast. In 2075, for example, a catastrophic storm broke through the Delta Works, a vast system of dams, storm surge barriers, and dikes that had protected the low-lying Netherlands from the sea. Flooding spread so quickly and on such a scale that, within about 48 hours, some 90,000 people had died.

Millions fled to higher ground, rebuilding as best they could. But the inundated cities could never be resettled. The economy of the Netherlands was in ruins. The country's unique cultural heritage – its art, dairy farms, tulip fields, and polders –was irretrievably lost. And worse, the identity of the Dutch, their sense of fairness and equality, their pride in a country that had been made more than found, seemed like it too had vanished beneath the waves.

Most coastal cities didn't disappear all at once. Still, vast swathes of Alexandria, Bangkok, Chittagong, Dhaka, Miami, Shanghai, Venice, and many other cities, were soon too expensive to defend from the sea. Historic centers, ports, and financial districts survived where municipal, regional, and national governments cooperated to build surge barriers and pumps, to raise roads, or to restore wetlands. Elsewhere, insurance disappeared, mortgages shortened, drinking-water aquifers turned salty, and repeated floods made ordinary maintenance impossible.

The phrase "submerged city" became shorthand for a complicated, dystopian reality: a place still visible on maps, but losing homes, tax revenue, transport links, and confidence year by year.

To people in Mendoza and other desert cities, disappearing ice carried the opposite meaning. Water wasn't surging into our streets; it was disappearing into the mountains.

Granted, melting snow and rain supplied most of the Mendoza River's water. But glaciers had provided the rest. The glaciers mattered most when there wasn't much snow or rain – during La Niña events, for example.

At first, glacial melting actually increased the water in the Mendoza River. Then the glaciers passed peak water: the point at which they had declined to such an extent that they could no longer supply as much meltwater. Finally, by the end of the century, Southern Andean glaciers were too diminished to provide protection during multiyear droughts.

With support from Argentina's government, Mendoza tried to make every liter last longer.

Engineers enlarged storage basins away from the rivers so they could capture water during brief periods of abundant snowmelt, then release it during dry months. They covered canals and repaired leaking gates so that less water disappeared before reaching farms. Drip irrigation delivered water directly to plant roots. Treated wastewater irrigated crops and parks. Satellites and meters helped officials identify wells that were pumping more groundwater than permitted.

But efficiency couldn't create new water. And it tended to cause fresh problems.

Savings in one vineyard spurred new development elsewhere. Sealed canals reduced seepage that had helped recharge aquifers or sustain vegetation downstream. It felt like every success in water management created a new source of conflict – or a new environmental crisis.

My grandmother worked for the provincial water authority. When I was nine years old, she took me to the Potrerillos reservoir. I remember her pointing to pale bands of rock, layered above the waves. They marked where water had once stood.

Her lesson was simple enough for a child to understand. Mendoza was a diminished place, because the Earth's climate had changed. From now on, it would be harder for us to survive.

2060-2078: Arctic Destabilization

The Arctic warmed much faster than the planet as a whole.

Snow and sea ice reflect most of the sunlight that reaches them, and that cools their surroundings. But as the Arctic warmed, retreating snow and ice exposed more and more land and ocean, which were darker and reflected less sunlight. So, exposed land and water warmed the Arctic, melting still more snow and ice.

It was just one of several feedback loops that led the Arctic to heat up so quickly.

By the 2050s, the Arctic Ocean was nearly ice-free at the end of summer – at least in most years. Winter sea ice didn't disappear, but it became thinner, younger, and more mobile.

At first, some governments and corporations welcomed the retreat of Arctic sea ice.

It allowed oil companies to access previously unreachable oil and gas reserves, though it also strengthened storms that made those reserves dangerous to exploit. More importantly, it created new shipping opportunities. The Northern Sea Route above Russia and the passages through the islands of the Canadian Arctic shortened ship voyages between the Atlantic and Pacific, and kept them away from pirates or militants in the Middle East.

But sea ice remained dangerous even when it covered less area, and broken floes moved unpredictably. Fog, limited ports and rescue capacity, and powerful waves unlocked by the retreat of sea ice all raised shipping costs. Meanwhile, the loss of ice that had protected shorelines allowed storms to damage villages, fuel depots, and docks.

Geopolitical competition made the region even less attractive to shipping and oil companies. Russia, Canada, Denmark through Greenland, Norway, and the United States disputed navigation rules, military access, seabed resources, and responsibility for spills. The Bering Strait – the narrow entrance between the Pacific and Arctic oceans – became a strategic chokepoint. Collisions, sabotage, and military confrontations raised the risk of a major war between nuclear superpowers.

Many of the most destructive changes to Arctic environments unfolded on land. Permafrost had stored vast quantities of underground ice. When that ice melted, the ground above it sagged, or collapsed to form sinkholes and even lakes. Roads buckled, building foundations cracked, pipelines shifted, and runways became unsafe.

Repairs often failed because engineers tried to rebuild on unstable ground. Indigenous communities that had contributed almost nothing to global warming lost travel routes, ice cellars, homes, burial grounds, and sacred landscapes. Relocation programs could move buildings and residents, but money couldn't reproduce a coastline, a hunting route, or knowledge rooted in a particular place.

Frozen soils also stored roughly twice as much carbon as the preindustrial atmosphere. Most of that carbon has remained underground – for now – but thawing has exposed ancient plant and animal remains to microbes, which by consuming organic matter released carbon dioxide. In waterlogged soils with little oxygen, other microbes produced methane instead. Methane is a greenhouse gas that warms the Earth even more than carbon dioxide, but it doesn't stay in the atmosphere as long.

Permafrost emissions supercharged Arctic warming, which in turn led to even more melting, then more emissions. But because they came from natural sources and affected a sparsely populated part of the world, they were politically easy for national governments to ignore.

Boreal forests added another feedback loop. Hotter, drier summers sparked increasingly severe fires across Canada, Alaska, Scandinavia, and Siberia that couldn't be contained even with new, robotic forest management and firefighting systems. Many northern landscapes did grow more vegetation as temperatures and atmospheric carbon dioxide concentrations rose. But drought and fire often killed mature trees faster than new forests could establish.

Fires released carbon and burned the insulating organic layer above permafrost. Smoke crossed oceans and continents, darkened snow, worsened heart and lung disease, interrupted aviation, and turned summer skies a sickly orange from Toronto to Beijing.

By the 2070s, populations across the Northern Hemisphere regarded suffocating wildfire smoke and evacuations from forested areas as normal parts of summer weather. The impacts of wildfires on economic output seemed manageable, so governments mandated new air filters – or passed legislation to limit outdoor work and rebuilding in woodlands –- rather than reducing emissions.

2078-2100: The AMOC Shock

The climate event that most profoundly reshaped the Earth began in the North Atlantic.

In the early 2070s, a vast system of currents, known as the Atlantic Meridional Overturning Circulation (AMOC), still pushed warm water from the tropics to the northern reaches of the Atlantic Ocean. Evaporation at the surface of the ocean made this water especially salty, and its salt content made it heavier than surrounding water. In the North Atlantic, it cooled, sank, and returned south.

The formation of this "deep water" depended on temperature and salinity. That made it exquisitely sensitive to warming, shifts in rainfall, and meltwater cascading off the Greenland Ice Sheet.

Scientists in the early 21st century agreed that the AMOC would weaken, but debated how much it could slow before 2100. Computer models simulated that a severe weakening – let alone a shutdown – was unlikely even under extreme warming.

But other studies detected troubling signs that a tipping point could be just years away.

In 2078, instruments moored to the ocean floor measured an abrupt and unexpected decline in the strength of the AMOC. The currents didn't disappear completely, but within a decade they had weakened to such an extent that many scientists claimed they had, essentially, collapsed.

The consequences of this Ocean Breakdown, as people called it, intensified around the time I was born.

The AMOC had moved heat north from the equator, and westerly winds directed by Earth's rotation carried that heat over Europe. The sun warms Europe's land in the summer, so the effect didn't matter as much then. But in the winter, heat from the ocean kept European temperatures much warmer than those of North America at the same latitude.

Not anymore.

Summers across Europe kept heating up, but winters in the continent's north and northwest cooled down with shocking speed. In one week during the winter of 2089, temperatures plummeted to -13 °C in London, and -34 °C in Stockholm – not accounting for the wind chill. Now, energy systems had to prepare for heating emergencies and heatwaves in the same year.

Across vast stretches of the North Atlantic and European Arctic, sea ice began to expand and survive the summer melt. Oil rigs established above northern reserves were hastily relocated. Parts of the Northern Sea Route above Russia were again closed to shipping. Even some sections of the Greenland Ice Sheet stabilized.

The distribution of North Atlantic plankton and fish communities shifted, damaging fisheries around Iceland, Greenland, and western Europe. Across the northern fringes of Siberia, the ground stopped thawing, hardening a scarred and pockmarked landscape.

But the worst consequences of the Ocean Breakdown were felt far from the North Atlantic.

Rain belts and storm tracks shifted because currents in the Atlantic organized winds that blew far beyond the ocean itself. The West African and South Asian monsoons failed in some years, and moved in others. Beginning in the 2080s, droughts reminiscent of the Great Hunger repeatedly devastated food production across China, the Indian subcontinent, and the Sahel.

Widespread malnutrition set the stage for increasingly deadly outbreaks of epidemic disease.

The bacteria and viruses responsible for diseases such as dengue and cholera, which had killed millions in the previous century, caused some of these outbreaks. But more and more involved previously unknown microorganisms crossing over from animal hosts to people. AI systems connected these spillovers to the collapse of ecosystems, which had changed where many animals lived, and how many there were.

New respiratory diseases spread the most quickly, and killed the most people. Several emerged simultaneously in different parts of the world. The interaction of different diseases in malnourished and displaced communities led to tens of millions of deaths, every year.

Meanwhile, sea levels rose rapidly along parts of the North American east coast, because weaker currents caused water to pile up when it otherwise would have flowed north. Heat pooled around the tropics, worsening marine heat waves.

Rainfall increased across the southern and eastern Amazon basin, preserving or restoring parts of the rainforest. But South America's northern edge dried out.

After the Breakdown, farmers abandoned maize and wheat cultivation across parts of Eurasia as colder growing seasons and summer drying made harvests increasingly unreliable.

But AI systems had supercharged the development of genetically modified organisms, and extreme heat and drought had already spurred investment into climate-controlled agriculture. Food production declined in many regions, pushing up inflation and worsening malnutrition in poor communities.

Europe remained wealthy, technologically advanced, and home to hundreds of millions of people. But birthrates in many European countries had long been among the world's lowest. Now, migration to other continents, or from northern to southern Europe, accelerated the decline of neighborhoods and cities across Europe.

Across Europe, tourists visited deserted buildings and suburbs, as they once had in America's rust belt.

2086-2095: The Water Emergency and Political Fracture

By the 2080s, more and more communities struggled with water insecurity. There wasn't enough water – except when there was far too much of it.

Higher temperatures increased evaporation from soils and reservoirs, and parched crops required more moisture. Snowpacks melted earlier, while glaciers that had once released water during dry seasons had shrunk. Saltwater seeped into coastal aquifers, and deteriorating or overburdened electrical grids made pumping, treatment, and desalination less reliable. Rain increasingly fell in torrential downpours.

In Mendoza, the emergency arrived as a sequence of water allocation orders. The government formally prioritized drinking water, but cities, farms, wineries, mines, hydropower stations, and ecosystems all depended on the same rivers and aquifers.

Agriculture had historically used most of the province's developed water, so even small urban shortages spurred demands for large cuts to irrigation. Farmers replied that turning off a household tap for an hour was temporary, but withholding water from a mature vineyard could destroy decades of work. Nevertheless, provincial officials shortened irrigation seasons, paid growers to remove vines, prohibited new wells in exhausted aquifers, and purchased some old water rights for transfer to towns.

The oasis changed crop by crop. Wine grapes tolerated dry conditions better than many fruits, but extreme heat accelerated ripening, raised sugar faster than flavor developed, lowered acidity, and scorched exposed berries. Growers shifted vineyards to higher elevations, farther south, or toward varieties better suited to hotter conditions.

Wealthy estates installed shade cloth, sensors, efficient irrigation, and cooling equipment. Small producers sold land or stopped farming. The wine industry survived, but it wasn't the same. The wine-growing region moved and shriveled, leaving abandoned irrigation ditches, deserted towns, and ruined livelihoods in its wake.

And the municipal government had to decide how much of its urban forest it could still support. At the beginning of the century, roughly 1,000 kilometers of acequias watered more than 600,000 trees across Mendoza. Their shade reduced the electricity needed for cooling.

Cutting irrigation would save water, while increasing heat deaths. Authorities did their best to replace thirsty plane trees and poplars with native molles, algarrobos, and other drought-tolerant species. But a young desert tree couldn't immediately reproduce the deep shade of an eighty-year-old canopy. Blocks that lost mature trees became hotter before the new landscape could grow.

Around the world, water sparked conflict. The stakes were especially high where rivers crossed borders.

During a severe drought in 2088, for example, China filled emergency reservoirs and expanded diversions in the upper Mekong and the Yarlung Tsangpo-Brahmaputra basin. That reduced or delayed downstream flows just as Vietnam, Laos, Cambodia, Thailand, India, and Bangladesh needed water most.

Diplomatic pressure, cyberattacks on dam controls, and military deployments followed. Along the disputed Himalayan border, Indian and Chinese forces exchanged escalating drone strikes, until Beijing agreed to reduce its diversions and release more water into the Brahmaputra.

By the 2080s, water insecurity imperiled many communities. And changes in the moisture content of the atmosphere increasingly exacerbated the effects of heat to kill people directly.

The human body cools itself mainly by evaporating sweat. High humidity slows evaporation, while direct sun, low wind, age, illness, dehydration, and physical labor lower the temperature a person can safely endure.

Early discussions often treated a wet-bulb temperature of 35 °C – a measurement combining heat and humidity – as a universal survival limit. Later research showed that many people could die under cooler or drier conditions, especially the elderly, people with chronic conditions, and outside laborers.

In 2090, persistent high pressure systems known as *heat domes* emerged and repeatedly reformed across a vast stretch of West Africa, the Persian Gulf, and South Asia. Amid unprecedented welt-bulb temperatures that, in many cities, exceeded 30 °C even at night, electricity demand far exceeded supply. Some power plants reduced output because their cooling water became too warm. Transmission equipment failed, and backup generators ran out of fuel. Hospitals lost refrigeration, water systems lost pressure, and millions of people slept outside because concrete buildings retained heat through the night.

No reliable death count was possible. Bodies were buried without records. Migrant workers simply disappeared from payrolls. Deaths from kidney failure, heart disease, contaminated water, or interrupted medical care weren't always logged as heat-related. Later estimates ranged from 6 million to 9 million direct and indirect deaths. Many survivors suffered lasting kidney, heart, and neurological injuries. Some lost their livelihoods when construction sites, ports, farms, and factories closed.

And the disaster broke what remained of global climate diplomacy.

Ethiopia, Kenya, Iran, Pakistan, and other states organized a Climate Justice Emergency Bloc that boycotted United Nations climate meetings. Their governments argued that the high-emitting states had demanded restraint from poorer countries while refusing to fund safe housing, reliable power grids, and water systems.

Wealthy countries replied that their voters wouldn't support open-ended financial or technology transfers during domestic emergencies. The UN climate framework survived on paper, but lost the ability to coordinate global mitigation or adaptation policies.

2095-2100: Everyone Became a Climate Loser

For a time, commentators divided the world into climate winners and climate losers.

Canada, Russia, Scandinavia, and a few high-altitude regions were expected to gain longer growing seasons, lower winter heating costs, and access to new resources. And indeed, some gains did unfold as expected. Agricultural lands *did* move north. Ports remained ice-free longer. Land values rose in places once considered too cold for comfort.

But even many genetically modified crops struggled in the thin, acidic, rocky, or waterlogged soils of the new, northern farms. Pests and plant diseases also moved north. Boreal fires destroyed timber, towns, and power lines. Thawing permafrost damaged infrastructure.

Migrants arrived faster than housing, schools, clinics, and water systems could expand. Even fortified borders couldn't keep them out. Countries that remained physically cooler still depended on tropical crops, foreign factories, global shipping, stable finance, and political order elsewhere.

It soon turned out that economic models had underestimated the impacts of simultaneous, mutually reinforcing extremes in temperature, precipitation, and wind.

A heatwave didn't just raise temperatures; it increased the likelihood of drought and wildfires. When it ended, it didn't give way to "normal" weather, but rather severe rains and unprecedented winds. Then another heat wave would begin.

Weather extremes didn't just kill people in a particular place. They raised food prices, discouraged tourism, damaged economies, worsened disease, weakened governments, and spurred migration.

A coastal flood, for example, closed ports and factories, delayed medicines, and interrupted the supply of transformers, pumps, and electronic controls needed to repair electrical grids. A heatwave slashed labor hours in construction, farming, transport, and mining precisely when societies needed to build the most infrastructure.

Repeated shocks also changed investment: money flowed toward emergency repairs and private protection rather than schools, research, maintenance, and long-term adaptation.

Ultimately, there were no winners – because it turned out we were all connected. If only we'd come to that realization earlier.

By the 2090s, global greenhouse gas emissions were finally falling – not because climate policies were succeeding, but because economies had contracted, populations had declined, and some industrial systems no longer functioned reliably. This was not an orderly decarbonization. Carbon dioxide concentrations remained high, permafrost and damaged forests continued to release carbon, and the world hadn't come close to reaching net zero emissions.

Today, Earth has warmed by about 4 °C, relative to its temperature in the late 19^{th} century. And there's little sign that the warming will stop anytime soon.

So far, humanity *has* survived, but only through desperate adaptations that, for most people, have made life poorer, more precarious, and shorter.

Many governments ration electricity, water, and food. They have closed borders, criminalized movement, and withdrawn public services from regions judged too costly to protect. Robots perform outdoor work, especially in the summer. Quarantines are a regular part of life.

Global civilization hasn't collapsed – not yet. But governments, communities, ecosystems, and entire ways of life certainly have. Death is everywhere, and nobody takes the future for granted.

We know one thing for sure. The lush and stable Earth our ancestors once enjoyed is never coming back.

2100: No Safe Latitude

Four degrees of warming didn't make the Earth uninhabitable – not exactly. It made habitability expensive, unequal, and, in many places, temporary.

A person could survive a Mendoza heatwave with reliable power, an insulated home, clean water, medical care, shade, and the freedom to stop working outdoors. Without those protections, the same heat could be lethal.

Mendoza remains a city. But it isn't the oasis it once was. Drinking water comes from a tightly monitored mix of river flow, groundwater, and recycled wastewater. Gardens are small, fountains rarely run, and open acequias carry water in scheduled pulses, rather than every day. The urban forest is thinner, and younger.

This evening, the sun is sinking behind the Andes through smoke from fires in the foothills. The air is a toxic, suffocating orange. The channel below my apartment has been dry for eleven days.

It's still 39 °C. But it's already the middle of April: autumn in the southern hemisphere. The power authority has warned that cooling may be cut after midnight.

The day is ending. It feels like the heat never will.