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About the Author

Bill Gates is a technologist, business leader, and philanthropist. In 1975, he cofounded Microsoft with his childhood friend Paul Allen; today he and his wife, Melinda, are cochairs of the Bill & Melinda Gates Foundation. He also launched Breakthrough Energy, an effort to commercialize clean energy and other climate-related technologies. He and Melinda have three children and live in Medina, Washington.

ALSO BY BILL GATES

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(with Nathan Myhrvold and Peter Rinearson)

Business @ the Speed of Thought
(with Collins Hemingway)

To the scientists, innovators, and activists who are leading the way

INTRODUCTION

51 Billion to Zero

There are two numbers you need to know about climate change. The first is 51 billion. The other is zero.

Fifty-one billion is how many tons of greenhouse gases the world typically adds to the atmosphere every year. Although the figure may go up or down a bit from year to year, it's generally increasing. This is *where we are today*.[fn1]

Zero is *what we need to aim for*. To stop the warming and avoid the worst effects of climate change—and these effects will be very bad—humans need to stop adding greenhouse gases to the atmosphere.

This sounds difficult, because it will be. The world has never done anything quite this big. Every country will need to change its ways. Virtually every activity in modern life—growing things, making things, getting around from place to place—involves releasing greenhouse gases, and as time goes on, more people will be living this modern lifestyle. That's good, because it means their lives are getting better. Yet if nothing else changes, the world will keep producing greenhouse gases, climate change will keep getting worse, and the impact on humans will in all likelihood be catastrophic.

But "if nothing else changes" is a big If. I believe that things *can* change. We already have some of the tools we need, and as for those we don't yet have, everything I've learned about climate and technology makes me optimistic that we can invent them, deploy them, and, if we act fast enough, avoid a climate catastrophe.

This book is about what it will take and why I think we can do it.

Two decades ago, I would never have predicted that one day I would be talking in public about climate change, much less writing a book about it. My background is in software, not climate science, and these days my full-time job is working with my wife, Melinda, at the Gates Foundation, where we are super-focused on global health, development, and U.S. education.

I came to focus on climate change in an indirect way—through the problem of energy poverty.

In the early 2000s, when our foundation was just starting out, I began traveling to low-income countries in sub-Saharan Africa and South Asia so I could learn more about child mortality, HIV, and the other big problems we were working on. But my mind was not always on diseases. I would fly into major cities, look out the window, and think, *Why is it so dark out there? Where are all the lights I'd see if this were New York, Paris, or Beijing?*

In Lagos, Nigeria, I traveled down unlit streets where people were huddling around fires they had built in old oil barrels. In remote villages, Melinda and I met women and girls who spent hours every day collecting firewood so they could cook over an open flame in their homes. We met kids who did their homework by candlelight because their homes didn't have electricity.

I learned that about a billion people didn't have reliable access to electricity and that half of them lived in sub-Saharan Africa. (The picture has improved a bit since then; today roughly 860 million people don't have electricity.) I thought about our foundation's motto—"Everyone deserves the chance to live a healthy and productive life"—and how it's hard to stay healthy if your local medical clinic can't keep vaccines cold because the refrigerators don't work. It's hard to be productive if you don't have lights to read by. And it's impossible to build an economy where everyone has job opportunities if you don't have massive amounts of reliable, affordable electricity for offices, factories, and call centers.

Melinda and I often meet children like nine-year-old Ovulube Chinachi, who lives in Lagos, Nigeria, and does his homework by candlelight.[1]

Around the same time, the late scientist David MacKay, a professor at Cambridge University, shared a graph with me that showed the relationship between income and energy use—a country's per capita income and the amount of electricity used by its people. The chart plotted various countries' per capita income on one axis and energy consumption on the other—and made it abundantly clear to me that the two go together:

Income and energy use go hand in hand. David MacKay showed me a chart like this one plotting energy consumption and income per person. The connection is unmistakable. (IEA; World Bank)[2]

As all this information sank in, I began to think about how the world could make energy affordable and reliable for the poor. It didn't make sense for our foundation to take on this huge problem—we needed it to stay focused on its core mission—but I started kicking around ideas with some inventor friends of mine. I read more deeply on the subject, including several eye-opening books by the scientist and historian Vaclav Smil, who helped me understand just how critical energy is to modern civilization.

At the time, I didn't understand that we needed to get to zero. The rich countries that are responsible for most emissions were starting to pay attention to climate change, and I thought that would be enough. My contribution, I believed, would be to advocate for making reliable energy affordable for the poor.

For one thing, they have the most to gain from it. Cheaper energy would mean not only lights at night but also cheaper fertilizer for their fields and cement for their homes. And when it comes to climate change, the poor have the most to lose. The majority of them are farmers who already live on the edge and can't withstand more droughts and floods.

Things changed for me in late 2006 when I met with two former Microsoft colleagues who were starting nonprofits focused on energy and climate. They brought along two climate scientists who were well versed in the issues, and the four of them showed me the data connecting greenhouse gas emissions to climate change.

I knew that greenhouse gases were making the temperature rise, but I had assumed that there were cyclical variations or other factors that would naturally prevent a true where success often comes quickly and there are fewer government regulations to deal with. Clean energy was a whole other ball game, and they were getting out.

Clearly, we needed to bring in new money and a different approach that was tailored specifically to clean energy. In September, two months before the Paris conference started, I emailed two dozen wealthy acquaintances, hoping to persuade them to commit venture funding to complement the governments' new money for research. Their investments would need to be long term—energy breakthroughs can take decades to develop—and they would have to tolerate a lot of risk. To avoid the potholes that the venture capitalists had run into, I committed to help build a focused team of experts who would vet the companies and help them navigate the complexities of the energy industry.

I was delighted by the response. The first investor said yes in less than four hours. By the time the Paris conference kicked off two months later, 26 more had joined, and we had named it the Breakthrough Energy Coalition. Today, the organization now known as Breakthrough Energy includes philanthropic programs, advocacy efforts, and private funds that have invested in more than 40 companies with promising ideas.

The governments came through too. Twenty heads of state got together in Paris and committed to doubling their funding for research. President Hollande, U.S. President Barack Obama, and Indian Prime Minister Narendra Modi had been instrumental in pulling it together; in fact, Prime Minister Modi came up with the name: Mission Innovation. Today Mission Innovation includes 24 countries and the European Commission and has unlocked $4.6 billion a year in new money for clean energy research, an increase of more than 50 percent in just a handful of years.

Launching Mission Innovation with world leaders at the 2015 UN climate conference in Paris. (See page 237 for the names of those photographed.)[3]

The next turning point in this story will be grimly familiar to everyone reading this book.

In 2020, disaster struck when a novel coronavirus spread around the world. To anyone who knows the history of pandemics, the devastation caused by COVID-19 was not a surprise. I had been studying disease outbreaks for years as part of my interest in global health, and I had become deeply concerned that the world wasn't ready to handle a pandemic like the 1918 flu, which killed tens of millions of people. In 2015, I had given a TED talk and several interviews in which I made the case that we needed to create a system for detecting and responding to big disease outbreaks. Other people, including former U.S. president George W. Bush, had made similar arguments.

Unfortunately, the world did little to prepare, and when the novel coronavirus struck, it caused massive loss of life and economic pain such as we had not seen since the Great Depression. Although I kept up much of my work on climate change, Melinda and I made COVID-19 the top priority for the Gates Foundation and the main focus of our own work. Every day, I would talk to scientists at universities and small companies, CEOs of pharmaceutical companies, or heads of government to see how the foundation could help accelerate the work on tests, treatments, and vaccines. By November 2020, we had committed more than $445 million in grants to fighting the disease, and hundreds of millions more via various financial investments to get vaccines, tests, and other critical products to lower-income countries faster.

Because economic activity has slowed down so much, the world will emit fewer greenhouse gases this year than last year. As I mentioned earlier, the reduction will probably be around 5 percent. In real terms, that means we will release the equivalent of 48 or 49 billion tons of carbon, instead of 51 billion.

That's a meaningful reduction, and we would be in great shape if we could continue that rate of decrease every year. Unfortunately, we can't.

Consider what it took to achieve this 5 percent reduction. A million people died, and tens of millions were put out of work. To put it mildly, this was not a situation that anyone would want to continue or repeat. And yet the world's greenhouse gas emissions probably dropped just 5 percent, and possibly less than that. What's remarkable to me is not how much emissions went down because of the pandemic, but how little.

This small decline in emissions is proof that we cannot get to zero emissions simply —or even mostly—by flying and driving less. Just as we needed new tests, treatments, and vaccines for the novel coronavirus, we need new tools for fighting climate change: zero-carbon ways to produce electricity, make things, grow food, keep our buildings cool and warm, and move people and goods around the world. And we need new seeds and other innovations to help the world's poorest people—many of whom are smallholder farmers—adapt to a warmer climate.

Of course, there are other hurdles too, and they don't have anything to do with science or funding. In the United States especially, the conversation about climate change has been sidetracked by politics. Some days, it can seem as if we have little hope of getting anything done.

I think more like an engineer than a political scientist, and I don't have a solution to the politics of climate change. Instead, what I hope to do is focus the conversation on what getting to zero requires: We need to channel the world's passion and its scientific IQ into deploying the clean energy solutions we have now, and inventing new ones, so we stop adding greenhouse gases to the atmosphere.

I am aware that I'm an imperfect messenger on climate change. The world is not exactly lacking in rich men with big ideas about what other people should do, or who think technology can fix any problem. And I own big houses and fly in private planes— in fact, I took one to Paris for the climate conference—so who am I to lecture anyone on the environment?

I plead guilty to all three charges.

I can't deny being a rich guy with an opinion. I do believe, though, that it is an informed opinion, and I am always trying to learn more.

I'm also a technophile. Show me a problem, and I'll look for technology to fix it. When it comes to climate change, I know innovation isn't the only thing we need. But we cannot keep the earth livable without it. Techno-fixes are not sufficient, but they are necessary.

Finally, it's true that my carbon footprint is absurdly high. For a long time I have felt guilty about this. I've been aware of how high my emissions are, but working on this book has made me even more conscious of my responsibility to reduce them. Shrinking my carbon footprint is the least that can be expected of someone in my position who's worried about climate change and publicly calling for action.

In 2020, I started buying sustainable jet fuel and will fully offset my family's aviation emissions in 2021. For our non-aviation emissions, I'm buying offsets through a company that runs a facility that removes carbon dioxide from the air (for more on this technology, which is called direct air capture, see chapter 4, "How We Plug In"). I'm also supporting a nonprofit that installs clean energy upgrades in affordable housing units in Chicago. And I'll keep looking for other ways to reduce my personal footprint.

I'm also investing in zero-carbon technologies. I like to think of these as another kind of offset for my emissions. I've put more than $1 billion into approaches that I hope will help the world get to zero, including affordable and reliable clean energy and low-emissions cement, steel, meat, and more. And I'm not aware of anyone who's investing more in direct air capture technologies.

Of course, investing in companies doesn't make my carbon footprint smaller. But if I've picked any winners at all, they'll be responsible for removing much more carbon than I or my family is responsible for. Besides, the goal isn't simply for any one person to make up for his or her emissions; it's to avoid a climate disaster. So I'm supporting early-stage clean energy research, investing in promising clean energy companies, advocating for policies that will trigger breakthroughs throughout the world, and encouraging other people who have the resources to do the same.

Here's the key point: Although heavy emitters like me should use less energy, the world overall should be using *more* of the goods and services that energy provides. There is nothing wrong with using more energy as long as it's carbon-free. The key to addressing climate change is to make clean energy just as cheap and reliable as what we get from fossil fuels. I'm putting a lot of effort into what I think will get us to that point and make a meaningful difference in going from 51 billion tons a year to zero.

This book suggests a way forward, a series of steps we can take to give ourselves the best chance to avoid a climate disaster. It breaks down into five parts:

Why zero? In chapter 1, I'll explain more about why we need to get to zero, including what we know (and what we don't) about how rising temperatures will affect people around the world.

The bad news: Getting to zero will be really hard. Because every plan to achieve anything starts with a realistic assessment of the barriers that stand in your way, in chapter 2 we'll take a moment to consider the challenges we're up against.

How to have an informed conversation about climate change. In chapter 3, I'll cut through some of the confusing statistics you might have heard and share the handful of questions I keep in mind in every conversation I have about climate change. They have kept me from going wrong more times than I can count, and I hope they will do the same for you.

The good news: We can do it. In chapters 4 through 9, I'll break down the areas where today's technology can help and where we need breakthroughs. This will be the longest part of the book, because there's so much to cover. We have some solutions we need to deploy in a big way now, and we also need a *lot* of innovations to be developed and spread around the world in the next few decades.

Although I'll introduce you to some of the technologies that I am especially excited about, I'm not going to name many specific companies. Partly that's because I'm investing in some of them, and I don't want to look as if I'm favoring companies that I have a financial interest in. But more important, I want the focus to be on the ideas and innovations, not on particular businesses. Some companies may go under in the coming years; that comes with the territory when you're doing cutting-edge work, though it's not necessarily a sign of failure. The key thing is to learn from the failure and incorporate the lessons into the next venture, just as we did at Microsoft and just as every other innovator I know does.

Steps we can take now. I wrote this book because I see not just the problem of climate change; I also see an opportunity to solve it. That's not pie-in-the-sky optimism. We already have two of the three things you need to accomplish any major undertaking. First, we have ambition, thanks to the passion of a growing global movement led by young people who are deeply concerned about climate change. Second, we have big goals for solving the problem as more national and local leaders around the world commit to doing their part.

Now we need the third component: a concrete plan to achieve our goals.

Just as our ambitions have been driven by an appreciation for climate science, any practical plan for reducing emissions has to be driven by other disciplines: physics, chemistry, biology, engineering, political science, economics, finance, and more. So in the final chapters of this book, I'll propose a plan based on guidance I've gotten from experts in all these disciplines. In chapters 10 and 11, I'll focus on policies that governments can adopt; in chapter 12, I'll suggest steps that each of us can take to help the world get to zero. Whether you're a government leader, an entrepreneur, or a voter with a busy life and too little free time (or all of the above), there are things you can do to help avoid a climate disaster.

That's it. Let's get started.

CHAPTER 1

Why Zero?

The reason we need to get to zero is simple. Greenhouse gases trap heat, causing the average surface temperature of the earth to go up. The more gases there are, the more the temperature rises. And once greenhouse gases are in the atmosphere, they stay there for a very long time; something like one-fifth of the carbon dioxide emitted today will still be there in 10,000 years.

There's no scenario in which we keep adding carbon to the atmosphere and the world stops getting hotter, and the hotter it gets, the harder it will be for humans to survive, much less thrive. We don't know exactly how much harm will be caused by a given rise in the temperature, but we have every reason to worry. And, because greenhouse gases remain in the atmosphere for so long, the planet will stay warm for a long time even after we get to zero.

Admittedly, I'm using "zero" imprecisely, and I should be clear about what I mean. In preindustrial times—before the mid-18th century or so—the earth's carbon cycle was probably roughly in balance; that is, plants and other things absorbed about as much carbon dioxide as was emitted.

But then we started burning fossil fuels. These fuels are made of carbon that's stored underground, thanks to plants that died eons ago and got compressed over millions of years into oil, coal, or natural gas. When we dig up those fuels and burn them, we emit extra carbon and add to the total amount in the atmosphere.

There are no realistic paths to zero that involve abandoning these fuels completely or stopping all the other activities that also produce greenhouse gases (like making cement, using fertilizer, or letting methane leak out of natural gas power plants). Instead, in all likelihood, in a zero-carbon future we will still be producing some emissions, but we'll have ways to remove the carbon they emit.

In other words, "getting to zero" doesn't actually mean "zero." It means "near net zero." It's not a pass-fail exam where everything's great if we get a 100 percent reduction and everything's a disaster if we get only a 99 percent reduction. But the bigger the reduction, the bigger the benefit.

A 50 percent drop in emissions wouldn't stop the rise in temperature; it would only slow things down, somewhat postponing but not preventing a climate catastrophe.

And suppose we reach a 99 percent reduction. Which countries and sectors of the economy would get to use the remaining 1 percent? How would we even decide something like that?

In fact, to avoid the worst climate scenarios, at some point we'll not only need to stop adding more gases but actually need to start removing some of the gases we have already emitted. You may see this step referred to as "net-negative emissions." It just them. Only molecules made up of different atoms, the way carbon dioxide and methane are, have the right structure to absorb radiation and start heating up.

Carbon dioxide emissions are on the rise, and so is the global temperature. On the left you see how our carbon dioxide emissions from industrial processes and burning fossil fuels have gone up since 1850. On the right you see how the global average temperature is rising along with emissions. (Global Carbon Budget 2019; Berkeley Earth)[2]

So that's the first part of the answer to the question "Why do we have to get to zero?"—because every bit of carbon we put into the atmosphere adds to the greenhouse effect. There's no getting around physics.

The next part of the answer involves the impact that all those greenhouse gases are having on the climate, and on us.

What We Do and Don't Know

Scientists still have a lot to learn about how and why the climate is changing. IPCC reports acknowledge up front some uncertainty about how much and how quickly the temperature will go up, for example, and exactly what effect these higher temperatures will have.

One problem is that computer models are far from perfect. The climate is mind-blowingly complex, and there's a lot we don't understand about things like how clouds affect warming or the impact of all this extra heat on ecosystems. Researchers are identifying these gaps and trying to fill them in.

Still, there is a lot that scientists do know and can state with confidence about what will happen if we don't get to zero. Here are a few key points.

The earth is warming, it's warming because of human activity, and the impact is bad and will get much worse. We have every reason to believe that at some point the impact will be catastrophic. Will that point come in 30 years? Fifty years? We don't know precisely. But given how hard the problem will be to solve, even if the worst case is 50 years away, we need to act now.

We've already raised the temperature at least 1 degree Celsius since preindustrial times, and if we don't reduce emissions, we'll probably have between 1.5 and 3 degrees Celsius of warming by mid-century, and between 4 and 8 degrees Celsius by the end of the century.

All this extra heat will cause various changes in the climate. Before I explain what's coming, I have to give you one caveat: Although we can predict the course of broad trends, like "there will be more hot days" and "sea levels will go up," we can't with certainty blame climate change for any particular event. For example, when there's a heat wave, we can't say whether it was caused by climate change alone. What we can do, though, is say how much climate change increased the odds of that heat wave happening. For hurricanes, it's unclear whether warmer oceans are causing a rise in the number of storms, but there is growing evidence that climate change is making storms wetter and increasing the number of intense ones. We also don't know whether or to what extent these extreme events will interact with each other to produce even more serious effects.

What else do we know?

For one thing, there will be more really hot days. I could give you statistics from cities throughout the United States, but I'll pick Albuquerque, New Mexico, because I have a special connection with the place: It's where Paul Allen and I founded Microsoft in 1975. (Micro-Soft, to be totally accurate—we wisely dropped the hyphen and lowercased the *S* a couple of years later.) In the mid-1970s, when we were just getting started, the temperature in Albuquerque went over 90 degrees Fahrenheit about 36 times a year, on average. By mid-century, the city's thermometers will go over 90 at least twice as often every year. By the end of the century, the city could see as many as 114 days that hot. In other words, they'll go from one month's worth of hot days every year to three months' worth.

Not everyone will suffer equally from hotter and more humid days. For example, the Seattle area, where Paul and I moved Microsoft in 1979, will probably get off relatively easy. We might reach 90 degrees on as many as 14 days a year later this century, after having an average of just one or two a year in the 1970s. And some places might actually benefit from a warmer climate. In cold regions, for example, fewer people will die of hypothermia and the flu, and they'll spend less money to heat their homes and businesses.

But the overall trend points toward trouble from a hotter climate. And all this extra heat has knock-on effects; for instance, it means that storms are getting worse. Scientists are still debating whether storms are happening more often because of the heat, but they appear to be getting more powerful in general. We know that when the average temperature rises, more water evaporates from the earth's surface into the air. Water vapor is a greenhouse gas, but unlike carbon dioxide or methane, it doesn't stay in the air for long—eventually, it falls back to the surface as rain or snow. As water vapor condenses into rain, it releases a massive amount of energy, as anyone who has ever experienced a big thunderstorm knows.

Even the most powerful storm typically lasts only a few days, but its impact can reverberate for years. There's the loss of life, a tragedy in its own right that can leave survivors both heartbroken and, often, destitute. Hurricanes and floods also destroy buildings, roads, and power lines that took years to build. All of that property can eventually be replaced, of course, but doing so siphons off money and time that could be put into new investments that help the economy grow. You're always trying to catch up to where you were, instead of getting ahead. One study estimated that Hurricane Maria in 2017 set Puerto Rico's infrastructure back more than two decades.[4] How long before the next storm comes along and sets it back again? We don't know.

These stronger storms are creating a strange feast-or-famine situation: Even though it's raining more in some places, other places are experiencing more frequent and more severe droughts. Hotter air can hold more moisture, and as the air gets warmer, it gets thirstier, drinking up more water from the soil. By the end of the century, soils in the southwestern United States will have 10 percent to 20 percent less moisture, and the risk of drought there will go up by at least 20 percent. Droughts will also threaten the Colorado River, which supplies drinking water for nearly 40 million people and irrigation for more than one-seventh of all American crops.

Hurricane Maria set Puerto Rico's power grid and other infrastructure back some two decades, according to one study.[3]

A hotter climate means there will be more frequent and destructive wildfires. Warm air absorbs moisture from plants and soil, leaving everything more prone to burning. There's a lot of variation around the world, because conditions change so much from place to place. But California is a dramatic example of what's going on. Wildfires now occur there five times more often than in the 1970s, largely because the fire season is getting longer and the forests there now contain much more dry wood that's likely to burn. According to the U.S. government, half of this increase is due to climate change, and by mid-century America could experience more than twice as much destruction from wildfires as it does today.[5] This should be worrisome for anyone who remembers America's devastating wildfire season of 2020.

Another effect of the extra heat is that sea levels will go up. This is partly because polar ice is melting, and partly because seawater expands when it gets warmer. (Metal does the same thing, which is why you can loosen a ring that's stuck on your finger by running it under hot water.) Although the overall rise in the global average sea level—most likely, a few feet by 2100—may not sound like much, the rising tide will affect some places much more than others. Beach areas are in trouble, not surprisingly, but so are cities situated on especially porous land. Miami is already seeing seawater bubble up through storm drains, even when it isn't raining—that's called dry-weather flooding—and the situation will not get better. In the IPCC's moderate scenario, by 2100 the sea level around Miami will rise by nearly two feet. And some parts of the city are settling—sinking, essentially—which might add another foot of water on top of that.

Rising sea levels will be even worse for the poorest people in the world. Bangladesh, a poor country that's making good progress on the path out of poverty, is a prime example. It has always been beset by severe weather; it has hundreds of miles of coastline on the Bay of Bengal; most of the country sits in low-lying, flood-prone river deltas; and it gets heavy rainfall every year. But the changing climate is making life there even harder. Thanks to cyclones, storm surges, and river floods, it is now common for 20 to 30 percent of Bangladesh to be underwater, wiping out crops and homes and killing people throughout the country.

Finally, with the extra heat and the carbon dioxide that's causing it, plants and animals are being affected. According to research cited by the IPCC, a rise of 2 degrees Celsius would cut the geographic range of vertebrates by 8 percent, plants by 16 percent, and insects by 18 percent.[6]

For the food we eat, it's a mixed picture, though mainly a grim one. On the one hand, wheat and many other plants grow faster and need less water when there's a large amount of carbon in the air. On the other hand, corn is especially sensitive to heat, and it's the number one crop in the United States, worth more than $50 billion a year.[7] In Iowa alone, more than 13 million acres of land are planted with corn.[8]

Globally, there's a wide range of possibilities for how climate change could affect the amount of food we get from each acre of crops. In some northerly regions, yields could go up, but in most places they'll drop, by anywhere from a few percentage points to as much as 50 percent. Climate change could cut southern Europe's production of wheat and corn in half by mid-century. In sub-Saharan Africa, farmers could see the growing season shrink by 20 percent and millions of acres of land become substantially drier. In poor communities, where many people already spend more than half of their incomes on food, food prices could rise by 20 percent or more. Extreme droughts in China—whose agricultural system provides wheat, rice, and corn for a fifth of the world's population—could trigger a regional or even global food crisis.

Extra heat won't be good for the animals we eat and get milk from; it will make them less productive and more prone to dying young, which in turn will make meat, eggs, and dairy more expensive. Communities that rely on seafood will have trouble too, because not only are the seas getting warmer, they're also bifurcating—developing some places where the water has more oxygen and others where it has less oxygen. As a result, fish and other sea life are moving to different waters, or simply dying off. If the temperature rises by 2 degrees Celsius, coral reefs could vanish completely, destroying a major source of seafood for more than a billion people.

When It Doesn't Rain, It Pours

You might think that the difference between 1.5 and 2 degrees would not be that great, but climate scientists have run simulations of both scenarios, and the news is not good. In many ways, a 2-degree rise wouldn't simply be 33 percent worse than 1.5; it could be 100 percent worse. Twice as many people would have trouble getting clean water. Corn production in the tropics would go down twice as much.

Any one of these effects of climate change will be bad enough. But no one's going to suffer from just hot days, or just floods, and nothing else. That's not how climate works. The effects of climate change add up, one on top of the other.

As it gets hotter, for example, mosquitoes will start living in new places (they like it humid, and they'll move from areas that dry out to ones that become more humid), so we'll see cases of malaria and other insect-borne diseases where they've never appeared before.

Heatstroke will be another major problem, and it's linked to the humidity, of all things. Air can contain only a certain amount of water vapor, and at some point it hits a ceiling, becoming so saturated that it can't absorb any more moisture. Why does that matter? Because the human body's ability to cool off depends on the air's ability to absorb sweat as it evaporates. If the air can't absorb your sweat, then it can't cool you off, no matter how much you perspire. There's simply nowhere for your perspiration to go. Your body temperature stays high, and if nothing changes, you die of heatstroke within hours.

Heatstroke, of course, is nothing new. But as the atmosphere gets hotter and more humid, it will become a much bigger problem. In the regions that are most in jeopardy—the Persian Gulf, South Asia, and parts of China—there will be times of the year when hundreds of millions of people will be at risk of dying.

To see what happens when these effects start piling up, let's look at the impact on individual people. Imagine you're a prosperous young farmer raising corn, soybeans, and cattle in Nebraska in 2050. How might climate change affect you and your family?

You're in the middle of the United States, far from the coasts, so rising sea levels don't directly harm you. But the heat does. In the 2010s, when you were a kid, you might've seen 33 days a year when the temperature hit 90; now it happens 65 or 70 times a year. The rain is also a lot less reliable: When you were a kid, you could expect around 25 inches a year; now it might be as little as 22 or as much as 29.

Maybe you've adjusted your business to the hotter days and the unpredictable rain. Years ago, you invested in new crop varieties that can tolerate extra heat, and you've found work-arounds that let you stay inside during the worst part of the day. You didn't love spending extra money on these crops and work-arounds, but they're better than the alternative.

One day, a powerful storm strikes without warning. As nearby rivers spill over the levees that have held them back for decades, your farm gets flooded. It's the kind of deluge your parents would've called a hundred-year flood, but now you'd consider yourself lucky if it happened only once a decade. The waters wash away large portions of your corn and soybean crops, and your stored grain is soaked so thoroughly that it rots and you have to throw it away. In theory, you could sell your cattle to make up for the loss, but all your cattle feed has been swept away too, so you won't be able to keep them alive for long.

Eventually the waters recede, and you can see that the nearby roads, bridges, and rail lines are now unusable. Not only does that keep you from shipping out whatever grain you've managed to preserve; it also makes it harder for trucks to deliver the seeds you need for the next planting season, assuming your fields are still usable. It all adds up to a disaster that could end your farming career and force you to sell off land that has been in your family for generations.

It may sound as if I'm cherry-picking the most extreme example, but things like this are already happening, especially to poor farmers, and in a few decades they could be happening to far more people. And as bad as it sounds, if you take a global perspective, you'll see that things will be much worse for the poorest 1 billion people in the world—people who are already struggling to get by and who will only struggle more as the climate gets worse.

Now imagine you live in rural India, where you and your husband are subsistence farmers, which means you and your kids eat nearly all the food you raise. In an especially good season, you sometimes have enough left over to sell so you can buy medicine for your kids or send them to school. Unfortunately, heat waves have become so common that your village is becoming unlivable—it's not at all unusual to have several days in a row over 120 degrees—and between the heat and the pests that are now invading your fields for the first time, it's almost impossible to keep your crops alive. Although monsoons have flooded other parts of the country, your community has received far less rain than normal, making it so hard to find water that you survive off a trickling pipe that runs only a few times a week. It's getting even tougher to simply keep your family fed.

You've already sent your oldest son to work in a big city hundreds of miles away because you couldn't afford to feed him. One of your neighbors committed suicide when he couldn't support his family anymore. Should you and your husband stay and try to survive on the farm you know, or abandon the land and move to a more urban area where you might make a living?

It's a wrenching decision. But it's the kind of choice that people around the world are already facing, with heartbreaking results. In the worst drought ever recorded in Syria—which lasted from 2007 to 2010—some 1.5 million people left farming areas for the cities, helping to set the stage for the armed conflict that started in 2011. That drought was made three times more likely by climate change.[9] By 2018, roughly 13 million Syrians had been displaced.

This problem is only going to get worse. One study that looked at the relationship between weather shocks and asylum applications to the European Union found that even with moderate warming, asylum applications could go up by 28 percent, to nearly 450,000 a year, by the end of the century.[10] The same study estimated that by 2080 lower crop yields would cause between 2 percent and 10 percent of adults in Mexico to try to cross the border into the United States.

Let's put all this into terms that everyone who is experiencing the COVID-19 pandemic can relate to. If you want to understand the kind of damage that climate change will inflict, look at COVID-19 and then imagine spreading the pain out over a much longer period of time. The loss of life and economic misery caused by this pandemic are on par with what will happen regularly if we do not eliminate the world's carbon emissions.

I'll start with the loss of life. How many people will be killed by COVID-19 versus by climate change? Because we want to compare events that happen at different points in