Introduction

Desperation Point

December in California at one degree of warming: ash motes float lazily through the afternoon light as distant wildfires rage. This smoky "winter" follows a brutal autumn at one degree of warming: a wayward hurricane roared toward Ireland, while Puerto Rico's grid, lashed by winds, remains dark. This winter, the stratospheric winds break down. The polar jet splits and warps, shoving cold air into the middle of the United States. Then, summer again: drought grips Europe, forests in Sweden are burning, the Rhine is drying up. And so on.

One degree of warming has already revealed itself to be about more than just elevated temperatures. Wild variability is the new normal. Atmospheric patterns get stuck in place, creating multi-week spells of weather that are out of place. Megafires and extreme events are also the new normal—or the new abnormal, as Jerry Brown, California's former governor, put it. One degree is more than one unit of measurement. One degree is about the uncanny, and the unfamiliar.

If this is one degree, what will three degrees be like? Four?

At some point—maybe it will be two, or three, or four degrees of warming—people will lose hope in the capacity of current emissions-reduction measures to avert climate upheaval. On one hand, there is a personal threshold at which one loses hope: many of the climate scientists I

know are there already. But there's also a societal threshold: a turning point, after which the collective discourse of ambition will slip into something else. A shift of narrative. Voices that say, "Let's be realistic; we're not going to make it." Whatever *making it* means: perhaps limiting warming to 2°C, or 1.5, as the Paris Agreement urged the world to strive for. There will be a moment where "we," in some kind of implied community, decide that something else must be tried. Where "we" say: Okay, it's too late. We didn't try our best, and now we are in that bad future. Then, there will be grappling for *something* that can be done.

This is the point where it becomes "necessary" to consider the future we didn't want: solar geoengineering. People will talk about changing how we live, from diet to consumption to transportation; but by then, the geophysics of the system will no longer be on our side. A specter rears its head: the idea of injecting aerosols into the stratosphere to block incoming sunlight. The vision is one of shielding ourselves in a haze of intentional pollution, a security blanket that now seems safer than the alternative. This discussion, while not an absolute given, seems plausible, if not probable, from the vantage point of one degree of warming—especially given that emissions are still rising.

You may have heard something about solar geoengineering. It's been skulking in the shadows of climate policy for a decade, and haunting science for longer than that, even though it's still just a rough idea. But it is unlikely you imagined solar geoengineering would be a serious topic of discussion, because it sounds too crazy—change the reflectivity of the earth to send more sunlight back out into space? Indeed, it *is* a drastic idea.

We are fortunate to have rays of sunlight streaming through space and hitting the atmospheric borders of our planet at a "solar constant" of about 1,360 watts per square meter (W/m^2) where the planet is directly facing the sun. This solar constant is our greatest resource; a foundation of life on earth. In fact, it's not actually so constant—it was named before people were able to measure it from space. The solar constant varies during the year, day to day, even minute to minute. Nevertheless, this incoming solar energy is one of the few things in life we can count on.

Much of this sunlight does not reach the surface; about 30 percent of it gets reflected back into space. So on a clear day when the sun is at its zenith, the solar radiation might reach 1,000 W/m^2. But this varies

depending on where you are on the globe, on the time of day, on the reflectivity of the surface (ice, desert, forest, ocean, etc.), on the clouds, on the composition of the atmosphere, and so on. Because it's night half the time, and because the sun is hitting most of the earth at an angle, the average solar radiation around the globe works out to about 180 W/m^2 over land.[1] Still, this 180 W/m^2 is a bounty.

The point of reciting all these numbers is this: solar geoengineering amounts to an effort to change this math. That's how a researcher might look at it, anyway.

From one perspective, it sounds like complete lunacy to intentionally mess with something as fundamental as incoming solar radiation. The sun, after all, has been worshipped by cultures around the world: countless prayers uttered to Ra, Helios, Sol, Bel, Surya, Amaterasu, and countless other solar deities throughout the ages. Today, many still celebrate holidays descended from solar worship. And that worship makes sense—without the sun, there would be nothing. Even in late capitalism, we valorize the sun: people search for living spaces with great natural light; they get suntans; they create tourist destinations with marketing based on the sun and bring entire populations to them via aircraft. Changing the way sunlight reaches us and *all other life on earth* is almost unimaginably drastic.

But there are ways of talking about solar geoengineering that normalize it, that make you forget the thing being discussed is sunlight itself. The most discussed method of solar geoengineering is "stratospheric aerosol injection"—that is, putting particles into the stratosphere, a layer of the atmosphere higher than planes normally fly. These particles would block some fraction of incoming sunlight, perhaps about 1 to 2 percent of it. Stratospheric aerosols would change not only the amount of light coming down, but also the type: the light would be more diffuse, scattering differently. These changes would alter the color of our skies, whitening them to a degree that may or may not be easily perceptible, depending on whether you live in an urban area. The distortion would also affect how plants and phytoplankton operate. Certainly, this type of intervention seems extreme.

And despite the extremity of the idea, it's not straightforwardly irrational. First of all, solar radiation is already naturally variable; a single passing cloud can change the flux by 25 W/m^2.[2] What's more, solar

radiation is *unnaturally* variable. Global warming is caused by greenhouse gas emissions—the greenhouse gas molecules trap heat, creating an imbalance between the energy coming in and the energy going back out. Since 1750, these emissions have increased the flux another 2.29 W/m^2.[3] This disparity between incoming and outgoing energy is what scientists call "radiative forcing"—a measure of imbalance, of forced change, caused by human activity. That imbalance would actually be greater—just over 3 W/m^2—if not for the slight countervailing effect of aerosol emissions that remain close to the ground. Think about a smoggy day. The quality of the light is dimmer. Indeed, air pollution from cars, trucks, and factories on the ground already masks about a degree of warming. Total removal of aerosols—as we're trying to accomplish, in order to improve air quality and human health—could induce heating of 0.5 to 1.1°C globally.[4]

So, from another perspective, because human activity is already messing with the balance of radiation through both greenhouse gas emissions (warming) and emitting particulate matter from industry and vehicles (cooling), it doesn't sound as absurd to entertain the idea that another tweak might not be that significant—especially if the counterfactual scenario is extreme climate suffering. If you stretch your imagination, you can picture a future scenario where it could be more outrageous *not* to talk about this idea.

The question is, are we at the point—let's call it "the shift"—where it is worth talking about more radical or extreme measures—such as removing carbon from the atmosphere, leaving oil in the ground, social and cultural change, radical adaptation, or even solar geoengineering?

Deciding where the shift—the moment of reckoning, the desperation point—lies is a difficult task, because for every optimist who thinks renewables will save the day, there is a pessimist noting that the storage capacity and electrical grid needed for a true renewable revolution does not even exist as a plan. For many people, it's hard to tell how desperate to feel: we know we should be worried, but we also imagine the world might slide to safety, show up five minutes to midnight and catch the train to an okay place, with some last-minute luck. It can seem like the dissonance around what's possible actually *increases* the closer we get to the crunch point; the event horizon. Some of this uncertainty is indeed grounded in the science. "Climate sensitivity"—the measurement describing how earth would

respond to a doubling of greenhouse gas concentrations from preindustrial times—is still unknown. That means we don't know precisely what impacts a given amount of greenhouse gas emissions will have.

However, basic physics dictates that this season of uncertainty is limited. The picture will become clearer as emissions continue, and as scientists tally up how much carbon is in the atmosphere. Nevertheless, examining the situation today provides useful insights that should be well known, but somehow are rarely discussed in venues other than technical scientific meetings.

At present, human activities emit about 40 gigatons (Gt) of carbon dioxide a year, or 50 Gt of "carbon dioxide equivalent," a measure that includes other greenhouse gases like methane. (A gigaton is a billion tons.) Since the Industrial Revolution, humans have emitted about 2,200 Gt of CO_2.[5] Scientists have estimated that releasing another 1,000 Gt CO_2 equivalent during this century would raise temperatures by two degrees Celsius—exceeding the target of the Paris Agreement—meaning that 1,000 Gt CO_2 is, if you like, our maximum remaining budget (these are rough figures; it could be much less).[6] Knowing that today roughly 50 Gt of carbon dioxide equivalent is emitted, it is evident that emitters are on track to squander the entire carbon budget within the next 20 years. Moreover, the *rate* of warming is still increasing. This means that if the rate of warming slows down yet emissions remain at today's rate, in twenty years, two degrees of warming are essentially guaranteed.

What would it take to avoid this? To keep warming below two degrees, emissions will need to drop dramatically—and even go negative by the end of this century, according to scenarios assessed by the Intergovernmental Panel on Climate Change. Figure 1 shows a typical "okay future" scenario; one that would provide for a decent chance of staying within two degrees.

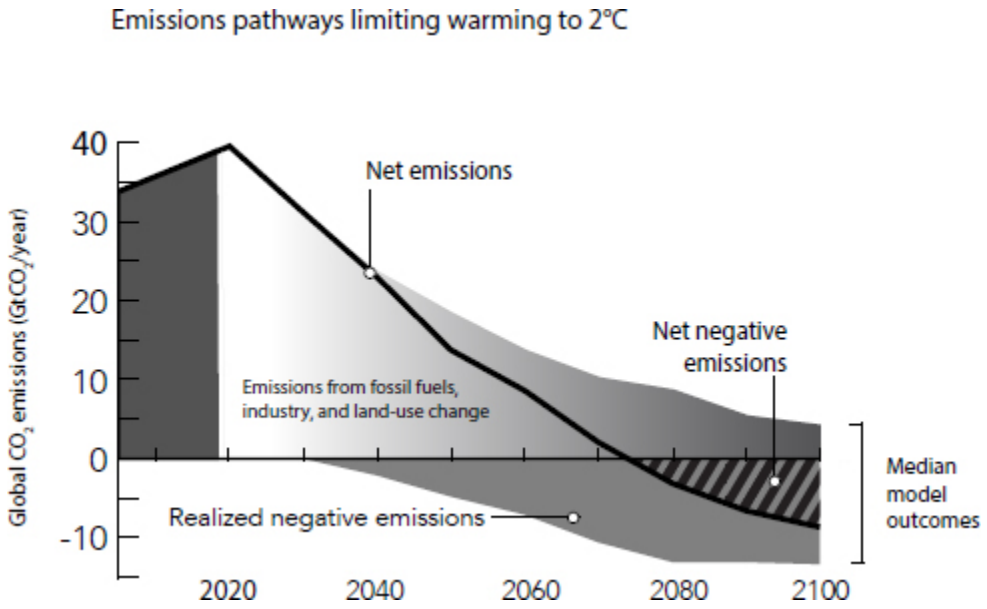

Figure 1. *Median values from 18 scenarios evaluated by six models using shared socioeconomic pathways assessed in the next assessment report of the Intergovernmental Panel on Climate Change. Data: Glen Peters / CICERO*

Three key features are evident in Figure 1.

First, the "good future" scenario has emissions peaking around 2020, and then dropping dramatically. Dramatic emissions reductions are key to any scenario that limits warming.

Second, emissions go net negative around 2070. "Net negative" means that the world is sucking up more carbon than it is emitting. How is that done? While emissions can be zeroed via the mitigation measures we're familiar with—using renewable energy instead of fossil fuels, stopping deforestation, halting the destruction of wetlands, and so on—to push emissions beyond zero and into negative territory requires a greater degree of intervention. There are two main categories of approach: biological methods, including using forests, agricultural systems, and marine environments to store carbon; and geologic methods, which typically employ industrial means to capture and store CO_2 underground or in rock. Some approaches combine these, though: for instance, coupling bioenergy with carbon capture and storage. (We'll walk through these different practices in detail later.)

But here, note a third point: carbon actually *starts* to be removed in the 2020s and 2030s, when emissions are still relatively high. Industrial carbon capture and storage (CCS)—the practice of capturing streams of carbon at

industrial sites and injecting it into underground wells—is a crucial technique for accomplishing these levels of carbon removal. As of 2019, the world has only around twenty CCS plants in operation, a number that is almost quaint in scale. To begin removing carbon at the level displayed in Figure 1 implies scaling up the current amount of carbon stored by something like a thousandfold. By 2100, in this scenario, the world would be sequestering ten or fifteen gigatons of carbon dioxide equivalent. And the scale-up begins right away.

The gentle slope of declining greenhouse gases looks so neat and calm. It is a fantasy described in clean lines; in the language of numbers, the same language engineers and builders and technocrats speak. This language lends weight to the image, making it seem less fantastic. However, this scenario relies on carbon removal technology at a scale far beyond the demonstration projects being planned today. As the Intergovernmental Panel on Climate Change (IPCC) warned in its special report on 1.5°C, reliance on such technology is a major risk. But the same report indicated that all the pathways analyzed depended upon the removal of between 100 and 1,000 gigatons of carbon in total.[7] In short, limiting warming to 2°C is very difficult without some use of negative emissions technologies—and 1.5°C is virtually unattainable without them.

Does this mean it is impossible to avert two degrees of warming? No. For we know plenty of practices that can be used to remove carbon. We can store it in soils, in building materials and products, in rock. After all, it's a prevalent element upon which all life is based. It would be difficult to scale these practices under our current economic and political logic, as we'll explore this book. But it's technically possible to imagine a future like the one depicted in Figure 1—a future where the excesses of the past (our present) are tucked away, cleaned up, like a stain removed. Some call this vision "climate restoration": the idea that we could use carbon removal technologies and practices to draw down carbon dioxide concentrations from the current 410 parts per million (ppm), down to the 300s, or even back to preindustrial levels. This vision undoubtedly strikes many as grandiose, and perhaps as unnecessary: after all, in many economies in the global North, emissions look to be plateauing or even declining.

If emissions *do* peak in the next decade, does that mean we're safe?

2030s

You're sitting at the kitchen table. It's hot. The radio says: "… and in Bonn today, negotiators hammered out a new agreement on differentiated responsibilities for carbon removal. We're also hearing rumors of a blockchain-based system of accounting to track international carbon flows.

"Meanwhile, at the Detroit Auto Show, yet another manufacturer has announced that their fleet will be all-electric by 2032. Following the rollout of Tesla's heavy trucks, Škoda has unveiled the design …"

You turn to your tablet, scrolling through your feeds as you sip your coffee. A picture of bright-red apples harvested from the student-run orchard: you press Like. Someone has posted an article with the headline "Emissions Peak Is Only a Plateau," subtitled: "The Low-Hanging Mitigation Fruit Has Been Picked—Now the Hard Work Begins." You want to read it and comment, so that the poster will know you're smart enough to follow what they post—but it sounds like a downer.

If you think the actions on climate will basically work out, turn to the next page.

If you think it's all just talk, performance, showmanship, turn to page 10.

2040s

Ten years, five months, and eighteen days later, you walk over to the kitchen table with fresh slices of slightly burnt toast. Your spouse doesn't look up. "What are you reading?" you ask.

"It's an article that looks at our success with climate change, and talks about how to apply it to public health and other global challenges." They chomp on the toast, leaving crumbs on the table. "We actively phased out fossil fuel infrastructure, and improved energy efficiency. Afforestation, carbon farming, and wetland restoration policies were also huge. Historically unprecedented rates of land-use change to sequester carbon, three times faster than the conversion of forests to soybeans in previous decades."

"Mm-hmm," you say. "Thank god the ag companies invested in climate change–resistant coffee strains." You have that feeling you get when it is late in the morning and you haven't accomplished very much yet.

"There was also the successful push toward carbon capture and storage. Back in 2017, they had only twenty-some CCS plants. But in 2020, with the global initiative on negative emissions, countries were putting in CCS facilities all over the place—and now there are over 2,000. In just a few decades."

"That's great," you say.

"The article is pretty techno-focused. It was really the social movements that created the push to hold the fossil fuel companies accountable, and that changed the narrative. I mean, when we were teenagers, everything was so apocalyptic. It was like some new climate disaster was in the air every day. Our kid isn't even going to know what that's like."

Turn to page 24.

You roll over in bed, throw off the faded sheet, and think about sitting up. Your kid is still asleep. *Thank god*. You ask: "Alexa, what do I need to know?"

"It's six twenty-three. Would you like your headlines?"

“Sure,” you say.

“A new paper in *Science* indicates that the world has warmed two degrees since the beginning of the Industrial Revolution. This threshold was crossed on the heels of the ongoing water emergency in Yemen. Meanwhile, the US House of Representatives is voting today on whether to join other countries in a geoengineering accord. Would you like to hear more of the story?”

“Sure,” you say, pulling on your socks.

“While emissions have slightly decreased in several regions, including the United States and China, they are still rising rapidly in other parts of the world. There’s disagreement around whether or not emissions have plateaued, and whether we are headed for 4°C of warming by the end of the century.”

“The geoengineering accord would establish an international cost-sharing agreement and insurance scheme that pools international resources for the deployment of stratospheric aerosols. Florida senator Jackie Gonzalez has been the first to speak out in favor of the accord. ‘If the melting of Greenland continues, Miami will be completely inundated in a few decades. It’s already impossible to insure the property along our coasts. The world has offered us a reasonable path to salvation, one that will be mutually beneficial for coastal cities all around the world. This accord could preserve geopolitical stability abroad as well as protect our homeland.’ However, several key members of the US Congress have remained silent. We can expect the results to be challenged in the courts either way.”

You head for the kitchen table and pick up your tablet, even though you’ve made a resolution not to look at it first thing in the morning anymore—anyway, it’s not really first thing if you’re out of bed. You have three notifications from friends, all auto-sent from an environmental NGO, asking you to call your representatives to protest the geoengineering accord. *We need polluters to pay for climate cleanup—not new risks for ourselves and our kids*. The photo of the smiling family looks like it could have been shot in your neighborhood. *Sigh*—the email is one of those that is custom-tailored based on your social media profile, which means there’ll be nostalgic nods to the protest activities of your teenage years, too, and pictures of your younger self. *Remember when you marched on Washington for climate justice in ’27? Now that you’re a parent, you’ve got even more*

to fight for! Put fossil fuels out of business. Stop solar geoengineering NOW!

If you choose to call your representatives in protest, flip a coin. Heads: turn to page 12; tails: turn to page 13.

If you think the geoengineering accord sounds like a pretty good option, turn to page 15.

2050s

You take your sandwich out of its wrapper: a few slices of cultivated meat and a flat tomato from your building's greenhouse.

You stay inside for lunch. A few die-hard coworkers are eating on the benches outside, but they're going to return to the office drenched in sweat. The downside of your choice is that there is a TV blaring. Today's lunchtime news talk show is about negative emissions.

"Whose negative emissions are these, really?" asks the moderator. "The ecologist from Nature Conservation says that they're her negative emissions, because she's worked with landowners in Iowa for over a decade to remove this carbon. But it seems like you, Ron, are saying that they're *your* negative emissions—that her work happens so that you at LowC Fuels can produce more fuel."

"In a sense, yes. But we're doing this in service of society." Ron leans back in his chair. "Look, Jim, these negative emissions can't *belong* to anyone, because by definition they don't exist. They're negative. And it's our job to keep these airplanes flying. That means we have to emit a little, and remove a little."

The ecologist cuts in. "Well, I didn't spend my career in the fields, teaming up with hardworking ranchers to reform farm practices, so that you could continue to pile up profits. Not after your industry spent *decades* obscuring the *very existence* of climate change."

So far, the on-screen needle recording audience sentiment has favored the energy spokesperson, who has taken up the voice of sensibility; but now it begins to tilt in favor of the ecologist. You pull out your phone to send in your sentiment. You get distracted by images of drowned refugee corpses in the Mediterranean, and then by the liquid eyes of a now-extinct species of forest mouse. It's a good thing climate sensitivity turned out to be low and those Antarctic glaciers have been so hardy, you think, polishing off your minimal sandwich.

Turn to page 24.

You eat your sandwich at your desk. Your terminal is monitoring you to make sure you eat your sandwich in a reasonable amount of time.

It is the anniversary of your child's death. On your desk is a picture of her, standing on the shore, clutching a red balloon. It was taken before the hurricane hit.

You see her when she had dengue fever. Waiting in the hospital lines, sleeping in your arms, breathing hard. *You should have done something more*. Your chatbot therapist tells you these thoughts are unhelpful, but you can't exorcise them.

You crumple up the wrapper from your sandwich and sweep the crumbs into the trash. The face of your chatbot therapist appears on the screen. "Good afternoon. It looks like your blood pressure has risen somewhat. Are you feeling okay?"

"Must be a nanosensor glitch."

She blinks at you, slowly. "Would you like to talk about it?"

"I'm just thinking that we should have done something more."

"I'm not sure what you mean. Can you tell me more?"

"I mean, we should have stopped the decline before it got this bad and everyone started dying all around us."

"It's not your fault, you know."

"That's what you always say, CB. You should try to mix it up."

"Okay. Thanks for your suggestion. I've noted your response." The therapist blinks again, attentively. You've observed that she is programmed with at least six types of blinks. "You know, a lot of other people are feeling bad about climate change too. Thirty-six percent of them have talked with me this week about climate change."

"I know."

"Maybe it would help to go to the exercise room and video chat with one of them."

You sigh. Once the therapist suggests this, you normally have to do it, because they notice if you ignore the suggestion too often. "I just feel like if there was anything I could do to stop it, I would. To put things back."

"There wasn't anything that anyone could have done. At the climate emergency summit in 2048, all the options were reviewed. Climate sensitivity was high. Last-ditch options like solar geoengineering were

found to be too risky and contentious. The best we can do is keep on going. Your loved ones would want that."

"Nobody wanted the liability," you mutter. "Bunch of cowards. Fuck it. I'm going to the exercise room."

Your therapist brightens her concerned eyes and blinks energetically. "Good idea!"

Turn to page 24.

You're in the doctor's waiting room. On screen, the first planes are going up. No one is paying attention; everyone's kids are miserable. Your child's breathing is slow and heavy. She won't even take a bite of the sandwich you made her.

The screen cuts to a reporter on a college campus: buildings of steel and glass, upon a patch of brown, withered grass. "The provisions in the accord say that we have to stick to the schedule for drawing down carbon, or we'll be stuck with this forever. Let's hear the word on the street."

She turns to two young men. "This is Dave and Jason. Guys, the geoengineering program starting today says that your generation, and your kids' generation, are going to be responsible not just for cutting carbon emissions, but for engaging in carbon management."

"Carbon management? Is that a major? I'm here for virtual game design," one boy says.

His friend shakes his head. "Come on. Carbon management is, like, waste management. Sure. Why not?"

The reporter nods. "We're talking about using even more technologies that remove carbon, because if we don't, we'll have to keep up the solar geoengineering forever. What do you think?"

"If you can make it a game, I'm in," the first boy says, smiling to the camera and the interviewer.

His friend pauses. "I think it sounds like a lot of responsibility, and, you know, they're leaving us with a lot of debt and not much social security. Like my mom was supposed to be getting social security, but it ran out, so she has to live with my sister. When I finish school, it'll be my turn to take her in, and I gotta find a place with two whole rooms that I can afford. So I don't know how we're supposed to have the resources to manage all this

carbon and stuff. We can't even get good jobs. Our parents don't even have houses. So I don't know about that.

You turn away, stroke your fevered kid's damp hair.

If you think that the world is finally going to draw down the carbon, continue on the following page.

If you're not sure it will, turn to page 19 or 22.

2070s

“No more stories,” you tell your grandson and granddaughter. “It’s really time for bed.”

“I want to hear ‘Amelia and the Carbon Monster’ next,” your grandson insists, struggling with his purple pajamas.

“Okay, just one more story.” You settle onto the pillows and the children clamber around you, all limbs and angles. “Amelia and the Carbon Monster,” you announce, taking a deep breath.

“Amelia was walking to school one day when she found a box on the sidewalk. She opened up the box, and there was a pair of magic glasses!” You have read this story so many times you could sleepwalk through it: Amelia, with her magic glasses, can see the invisible carbon monster. Amelia pulls together her team of Special Investigators. They devise all these ways to dissolve the carbon monster: they plant the 10 billion trees, build the beautiful new cities from special wood, and design the machines that take carbon out of the air and put it deep underground. Meanwhile, the Scientific Committee builds the Stratospheric Shield, so that the team has time to do their work.

“By the time they were finished, they were old, and the playground where they used to meet had become a meadow. Amelia took out her magic glasses and looked around. The trees and dirt and plants and buildings were all filled up with carbon, glowing with a soft light. The end.” You close the book. Your feet have fallen asleep, and your grandson has a glassy-eyed look.

Your granddaughter still looks somewhat alert. “That’s not a true story, is it?”

“It’s not exactly true. But it’s true in spirit,” you say.

“How can carbon be a monster if it’s everywhere?”

“Well, carbon’s not a monster. The people who wanted to burn too much of it and get rich were kind of like monsters. The point of the book is the teamwork that had to go into cleaning up the carbon pollution. Even though

it’s not all cleaned up yet, we’re halfway there. Pretty soon we might be able to take down the Stratospheric Shield.”

“I don’t like cleaning up.”

“Yeah. But this is about changing your attitude. Cleaning up can be really fun, if you do it with your friends,” you explain. “You know when you do cleanup time at school, and it’s like a race? It can be like that. You were really my little cleanup helper when you were two.”

Your granddaughter has lost interest. “I want to play with my mini forest now.”

“No,” you say, “it’s time for bed.” They will sleep well.

Turn to page 24.

You’re getting ready for bed when there’s a knock on your door. You tap on the wall to call up video from the hall: a professional-looking duo in bright sky-blue suits. They can’t be Mormons, you think, with suits that color.

“Good evening!” They are beaming. “We’re sorry to stop by so late,” the woman apologizes, “but this was predicted to be a good time.”

“What can I do for you?”

“We’re with a group called Blue Sky Again. Do you remember the color the sky used to be when you were a kid?”

“Sure I do. But how would you? You’re too young.”

“We didn’t grow up with true-blue skies,” the man says. “But I got the blue sunglasses when they came out. We try to connect with people who do remember, and we’d like to give you some information about how you can help.”

You sigh.

“You probably remember when the planes started going up.”

“Yeah.”

“Well, maybe you also remember the great enthusiasm for carbon removal around the time of the accord.”

“Sure, the planes were supposed to be temporary until we got the carbon out. That was the line. The world cut emissions by half, and decided that was good enough, I guess.” Your legs ache from the exercise machine and you begin to wonder if you should have opened the door.

“Well, we think that’s a crime. I see on the wall you have some pictures of little ones—grandkids? We think they should be able to see blue skies, too. We might never be able to, but they should. So we need to finish the job.”

You laugh. “That’s a very laudable cause for you to spend your evenings on. But why would people start on carbon removal again? And how?”

“I’m glad you asked the ‘how’ question. Our five-point plan, FINISH, answers that. We can project it on the wall.”

Bullet points appear beside your door. “The first step is Fund. They skipped this fifty years ago, so they never even got to the next steps. But now we have the Machine Labor Act. You’re familiar with that?”

“Well, I think so. Companies that automate have to put revenue into the Universal Basic Income program, proportional to how many jobs they automated. In order to spread the benefits of automation around a bit more.”

“Yes. We want to use that same model for funding further carbon removal. We can’t tax only the energy companies who combusted fossil fuels; after all, they’re the ones now providing our low-carbon fuels and carbon storage, and we need them to continue operating. But we do have a lot of wealth that was created in the tech sector during this century. What we’re proposing to do is to add a small additional tax on that wealth. It will hurt the bottom lines of the old mega-platforms, the old Apple-Amazon-Alphabets. But not too much—and many of these companies will get it back, if they choose to participate in carbon removal activities. They get a nanobonus for each ton removed. That’s our second step: Incentivize.”

“I’m not sure how any of the mega-platforms are really going to remove carbon themselves, though.”

“We know you grew up thinking of these as technology companies. But they’ve moved into transport, building, manufacturing, and all other sectors—you can see on this chart that these top four companies and their subsidiaries are responsible for a huge share of energy consumption. So there’s a lot they can do, and they’re the ones that have the revenue to fund carbon-negative infrastructure.”

You feel like you’ve been standing in your doorway for a very long time.

“So, it’s Fund, Incentivize—those two happen at the national scale. Then, to take this global, we need Negotiate, Inspire, and Show Heart.

Negotiation will work if we inspire other countries with our model and build goodwill. It's really our responsibility to make the first move. So, Negotiate, Inspire, and Show Heart. That final step is really important. The reason this didn't work before is because it was technocratic, and unemotional. But the human heart is really at the core of Blue Sky Again."

"I'm not sure what I can do about all of this," you tell her. "Honestly, I was just getting ready for bed…"

"It's that first step, Fund, that needs your help. These companies aren't going to fund the removal projects unless citizens speak out and show your demand for this. So we're asking you to join the movement. There are three concrete things you can do: you can talk with your elected representatives, share the key messages of FINISH, and vote."

You sigh. "I did all those things fifty years ago, and it didn't do a damn thing. And it would have been so much easier to fix then, before we'd put another several hundred gigatons in. We're addicted to these particles now." They both look a bit crestfallen. "I'm glad there's young people like you who care. But honestly, the world just doesn't work that way."

Turn to page 24.

You're crawling into bed and hear a distant blast; the windows vibrate. You get up and secure the sheeting taped over all the windows and doors. Then, you check your phone. There's the alert: *Residents within one hundred miles of Active Participation airstrips, shelter in place*.

Are you ok? It's a message from your child, 3,000 miles away.

Ok. Looks like I'll be indoors for a while, you write back. You hope the winds are going out to sea.

I wish you had evacuated and come over. You had considered it, but it would be a long journey for someone in your condition. It would also have exhausted the last of your savings, making you utterly dependent upon your child.

Then another message: *I can't believe they would do this*.

As they were growing up, you tried to cultivate a sense of hope in your child, hope for positive action and rationality—but they ended up being pretty naive, you reflect. The solar geoengineering program was believed to be a common good, out of reach of the low-level tangle of proxy wars. It was well known that stopping the program would cause a rapid temperature

rise of three or four degrees over the next few years, decimating food production. Mutually assured destruction, your parents had called it, and they seemed pretty comfortable with the idea that this was a workable arrangement. However, key demographics in both Russia and the US had been fed a steady, micro-targeted stream of propaganda: ending the program would cripple their enemies while making Russia and America glorious breadbaskets again. In the past month, verified videos showed rallies in the streets of Murmansk calling for leaders to end the program for good. Now it appears this idea has buy-in from the Russian regime, whose erratic incompetence makes you long for the calculating petro-oligarchs of your youth.

They don't live in the same reality as we do, honey, you write back. You wonder how long it would take to come to a sensible agreement and to restore the flights. Conventional wisdom used to be that you had a couple of years before the last of the particles fell out and the warming began—plenty of time to manufacture more planes and set up more airstrips. A bunch of reserve aircraft under a mountain in Colorado were stored just for this purpose. But the wars of the past few decades have taken a toll on all components of the system. Refineries blink out of commission; key metals are difficult to obtain; transportation infrastructure for moving commodities around on time is a disaster. The computers running it all are routinely hacked. It is like humanitarian work in Central Africa used to be: so many deaths could have been prevented by a basic medicine that you could find in any American pharmacy, and yet there was no way of attaining it. A different set of rules for what was possible seemed to apply. These days, it is getting to be the same way all over the world. The simplicity of manufacturing a jet, building an airstrip, fueling it, and supplying it with liquid sulfur compounds was one of those things that could be reliably executed at one point in time. Yet conditions have shifted; once-simple feats are today confounded by a number of different events. Hopefully China will still work this out, you think. You roll over in bed.

Your phone vibrates again. *I'm scared*, your grown child writes. From a continent away, you don't know how to answer. When they were young, a hug would fix it. Now, your survival depends on the rationality and goodwill of human beings you don't know. You think back to the slaughter of the wars of the past century, of the slide of your own country into brute falsehoods and racism and hatred of the other—history is not reassuring on

this count. You try to dredge up a memory of what humans have said or thought when faced with absolute darkness, some sentiment from a great historical or philosophical or spiritual leader, but your mind is maddeningly blank.

I'm still here is the only reply you can muster. Then, another blast.

Turn to the next page.

What can we glean from this brief adventure?

Geoengineering talk often focuses on one moment—the decision to "deploy," and how or whether publics will be a part of this decision. But looking at prospective decision points muddies this notion of a discrete decision. It's also not clear exactly who these "decision makers" are. In much of our conversation about climate action, the citizen becomes a witness to history, to decision ceremonies of the powerful. Out of view are the backstories, the tiny actions that accumulated into a formal decision. It becomes hard to imagine otherwise—that geoengineering could be carried out in conversation with civil society, much less led *by* us.

Right now, geoengineering doesn't exist. Indeed, the concept is an awkward catch-all that bears little correspondence with the things it purports to describe. The UK's Royal Society laid out the term in a 2009 report, which assessed both carbon dioxide removal and solar geoengineering, also known as solar radiation management. (For a deeper understanding of how the concept of "geoengineering" came about, Oliver Morton's book *The Planet Remade* and Jack Stilgoe's book *Experiment Earth* are excellent resources.) Subsequent policy and scientific research adopted the Royal Society's framing, though it's quite possible that in the near future, the marriage of these two approaches will dissolve: a 2019 resolution brought before the United Nations Environment Assembly to assess geoengineering failed in part because it combined such different approaches. This book does consider both carbon removal and solar geoengineering, even though they are very different, because both are imagined as ways of managing an overshoot of temperature targets. Though *geoengineering* is a keyword in this book, my hope is that it is a keyword that future generations will not recognize—not because they're living it and it's become an ordinary background condition, but because it's a weird artifact of the early twenty-first-century way of seeing the human

relationship with the rest of nature. This book contemplates what comes "after geoengineering" in the sense that it extends an invitation to think toward the *end goals* of geoengineering. "After geoengineering" also aims to evolve the conceptual language we use to apprehend what it means to intentionally change the climate: once "geoengineering" is a retired signifier, how do we understand these practices, and what does the new language and new understanding enable?

Even though climate engineering is mostly imaginary right now, it's a topic that's unlikely to disappear until either mitigation is pursued in earnest or the concept of geoengineering is replaced by something better; as long as climate change worsens, the specter is always there. In fact, some of the scarier scenarios result when geoengineering isn't implemented until the impacts of climate change are even more extreme, and is therefore conducted by governments that are starting to fray and unravel. Looking at these fictional scenarios as they unfold prompts some hard questions about the optimal timing of geoengineering. Climate policy at large has been influenced by a "wait and see" attitude, where policymakers wait and see what kinds of economic damage it will cause before taking action. Research shows that even highly educated adults believe this is a reasonable approach, possibly because their mental models don't properly apprehend stocks and flows.[8] Climate change is a problem of carbon stocks, not carbon flows: the earth system is like a bathtub, filling up (an analogy used by climate modeler John Sterman and educator Linda Booth Sweeney). Reducing the flow of water into the bathtub isn't going to fix our problem unless we're actually *draining* it, too: the amount of emissions can be reduced, but greenhouse gas concentrations will still be rising. Wait-and-see is actually a recipe for disaster, then, because more water is flowing into the bathtub every year. Carbon removal increases the drain. It doesn't make sense to wait and see if it's needed. Moreover, it is possible that our capacity to carry out carbon removal—economically, politically, and socially—could actually be greater now than it will be in a climate-stressed future.

Solar geoengineering is trickier. A wait-and-see approach makes intuitive sense: let's wait and see if society gets emissions under control in the next couple of decades, and let's wait and see if scientists can get better estimates of climate sensitivity and sink responses. However, there are two key limitations to note here. First, scientists anticipate that doing the

research on solar geoengineering could take at least twenty years, and possibly many decades. Second, we won't know about some of these climate tipping points until we've crossed them. Imagine implementing a solar geoengineering program in order to save coastal megacities from rising seas—a plausible reason a society might try something like this. It would be desirable to do the solar geoengineering before warming reached levels where the sea level rise was locked in. But that year might only be known in hindsight, given that it's a nonlinear system. For some, this is a rationale for at least starting geoengineering research right away. A counterargument is that research is a slippery slope, and doing the research makes it more likely that solar geoengineering will be deployed.

Whatever conclusion one arrives at in this debate, the main takeaway, for me, is this: There are certainly scenarios in which global society *does* figure out how to cut emissions to zero, albeit with much climate suffering (in the near future as well as our current present). Yet, if one thinks it's plausible that there won't be a significant start on this in the next decade, and that the risks of climate change are significant, it could be reasonable to look into solar geoengineering. And naturally one would want to avoid the worst-case and go for the better-case ways of doing it. There are crucial choices to be made about how it is done. For most climate engineering techniques, what is outrageous inheres not in the technology, but in the context in which it would be deployed.

Those contexts vary, but they all have two important elements. One is the counterfactual climate change scenario: How bad is climate change turning out to be, on a scale from pretty bad to catastrophic? The second is what is being done at the time to confront climate change, whether that be carbon removal, mitigation, adaptation—or nothing. These are *very* different futures, for reasons alluded to in the fictional scenarios you just navigated, and for reasons I'll go into throughout this book. The key point is that if a solar geoengineering program is to be ended on a meaningful timescale, it will rely on mitigation and carbon removal. If a regime begins solar geoengineering, it needs to keep putting those particles up there year after year, until carbon emissions are brought down. Thus, the hard thing isn't beginning the project, but ending it: ensuring that what comes *after geoengineering* is livable. This is a battleground that's currently obscured in most discussions of geoengineering.

The definitive story of the twenty-first century, for people working to combat climate change, may be captured in one graph: the rise of greenhouse gas emissions. The line features a dramatic, tension-laden rise—and, ideally, a peak, followed by a dramatic and then gentle downslope, a resolution that accords a feeling of restoration and completion. From Shakespeare to the novel to the life course, the exposition–conflict–climax–resolution–moral story arc is a classic one. It maps nicely onto a temperature-overshoot scenario, where emissions are temporarily high but come back down. This story line lands us, the challenged yet triumphant protagonist, with 2°C of warming at century's end. These established narrative forms are how we know how to locate ourselves in an overwhelming situation; how we manage to narrate the task at hand. In these imaginaries of managing an overshoot via carbon removal, we risk simply mapping our familiar narrative form onto the problem.

As philosopher Pak-Hang Wong argues, geoengineering needs to be seen "not as a *one-off event* but as a *temporally extended process*."[9] It's not about the hero's moment of action, the climax. I would add that this re-visioning of geoengineering must be directed not just into the future, but into the past as well, thereby placing climate intervention into historical context. Future processes of both solar geoengineering and carbon removal will entail dealing with compensation or insurance for people who suffer loss and damage, working out ways to protect vulnerable people, working out who pays for it—and all that requires a reckoning with history, particularly with colonial histories of land appropriation, dispossession, and exploitation. On the international level, negotiators will have to delve into the histories of uneven development, carbon debt, and, yes, colonialism. Carbon removal can be viewed in terms of debt repayment. The addition of solar geoengineering on top of carbon removal would therefore be like living with the repo man always in the sky above you, reminding you what happens if the debt isn't paid back. Financially, we are already living in a world of debt peonage, as Marxist geographer David Harvey points out; most of the population has future claims on their labor.[10] Now future generations are going to have a double debt. It's not just the decision to do geoengineering that matters; it's how this carbon debt and carbon cleanup operation is taken care of, too. The details are everything.

In reality, the resolution of this narrative curve is going to involve struggles all along the way. The latter part of the work, the last half of the

curve towards completion, may be tougher than the first, because decarbonizing the electricity sector by switching to solar panels is simply easier than dealing with "hard to mitigate" sectors or deep cultural changes, like decarbonization of aviation and industrial production, or reduction of meat consumption. Deciding to start geoengineering is a bit like deciding to get married. It's not saying the vows that is hard, but doing the work of the marriage. "Tying the knot," in reality, doesn't actually mean that you're going to stay together forever, despite the metaphor. You have to keep choosing your spouse, or the marriage deteriorates. Solar geoengineering, in particular, would be more like a relationship than a ceremony: and yet much of the treatment in the literature and the press focuses on the expensive wedding. We should instead be thinking more about the world *after* geoengineering, because climate engineering could be a means to very different ends.

Indeed, it has been difficult for environmentalists and the left to engage with either carbon removal or solar geoengineering in a forward-thinking way. Part of this is due to a fixation on the immediate need to see emissions peak—but part of it also has to do with some serious limitations in how we think.

Copenhagen, December 2009, 1°C / 34°F

The banners unfurled under the dreary skies read "Hopenhagen." I crossed the plaza, pigeons scattering. A historic brick building loomed above, its rooftop scaffolding bearing the logo: "i'm loving it." On the ground floor were a Burger King and KFC. Between this fast-food sandwich hung a three-story advertisement sponsored by "corporate citizens Coca-Cola and Siemens": two young, blonde boys, skinny and pale, with fists in the air, ready to heft a burden. "Earth's Bodyguards," read the caption.

I waited in the cold with hundreds of bundled-up delegates and protestors for a train to the Bella Center, where the fifteenth session of the United Nations Framework Convention on Climate Change's Conference of the Parties was taking place. We glided past a glassy office building with a several-story bright-green banner. "Stop climate change. Make COP 15 matter," it instructed us in Helvetica Light, the logo of construction corporation Skanska beneath.

At the time, climate politics seemed haunted by the specter of green capitalism. We marched under the slogan System Change Not Climate Change. While I have only a few distinct memories of this summit, they portended something quite different than our green capitalist, ecologically modernized future.

Between breaks, delegates would spill out of the conference rooms and rush to treat-laden tables in the hallways in a near melee for the best desserts. A European diplomat in a suit and a young student both reached for the last chocolate on the table, and the man in the suit slapped the confection out of the younger man's hand.

A retinue of men, dressed in suits, swept briskly through the corridor like a cold wind. The man in the center was the focal point; the rest flanked him, like a military formation. I flattened myself into the side of the hallway as they passed. It's an unremarkable thing, people passing each other in a nondescript corridor, but I felt chilled. "Did you see Robert Mugabe? He's here," someone whispered to me a few minutes later.

A tent, in the rain, in the "free city" of Christiania. I listened to Naomi Klein and other activists muster the forces. We drank mulled wine to keep warm and waited for the police to sweep in with their water cannons and tear gas; there was a rumor that they were coming. (They came.)

There was a kind of power that crackled in the air. Every time it manifested, it surprised me. I was expecting a climate summit to be a rather stuffy and formal affair, filled with acronyms and technical jargon. The injunctions of green capitalism postered around the city seemed pleading, thin, compared to these older and more primal forms of power. Hugo Chávez, speaking at the summit, said that "a ghost is stalking the streets of Copenhagen … it's capitalism, capitalism is that ghost." Chavez declared, "When these capitalist gods of carbon burp and belch their dangerous emissions, it's we, the lesser mortals of the developing sphere who gasp and sink and eventually die." I can understand the sentiment—particularly when it comes to the unevenness of climate impacts and the brutality of the historical record. As ecological Marxist theory argues, capital accumulation and the treadmill of production is a central factor in global environmental degradation—a thesis I'm onboard with. Nevertheless, I don't think that *green* capitalism was the ghost roaming those halls. Perhaps we were focusing on the wrong ghost.

Those of us schooled in keeping watch against green capitalism would naturally read geoengineering as capitalism's next move in self-preservation. I'm skeptical of this, because I don't see the evidence that capitalism is capable of acting in its own long-term benefit—especially not consciously, on the scale and temporality of mobilization that this intervention would require. (Although oil companies might be: a slightly different prospect that is discussed in Chapter 8.) But capital is something of a headless monster, incapable of this kind of macro-level, strategic, long-term thinking. In the face of what could be an existential crisis, innovation is flowing toward hookup apps and making sure porny advertising doesn't get stationed next to famous brands. This is where capital's attention and money is directed; as anthropologist David Graeber observes, technological progress since the 1970s has been largely in information technologies, technologies of simulation. Graeber notes that there was a shift from "investment in technologies associated with the possibility of alternative futures to investment in technologies that furthered labor discipline and social control"[11]—in other words, it's a big mistake to assume capitalism is naturally technologically progressive. In fact, he suggests, "invention and true innovation will not happen within the framework of contemporary corporate capitalism—or, most likely any form of capitalism at all."[12] I agree—we've seen numerous terrific ideas since the 1970s in alternative energy, and even in carbon removal, but they've been constantly thwarted or shelved. Whatever form of capitalism we're living in now, it doesn't seem like a system in which carbon removal is going to evolve. The derivation of capitalism we're coping with is predatory, inelegant, and fragmented, seemingly incapable of delivering fixed-capital tools like carbon capture and storage or transformative bioenergy to extend its lifespan.

Critical theorist McKenzie Wark asks: "We think within a metaphysical construct in which capital has some eternal inner essence, and only its forms of appearance ever change … But what if the whole of capitalism had mutated into something else?"[13] Wark speculates on the emergence of what he calls the "vectoralist" class, a new postcapitalist ruling class that owns and controls the means of producing information: the vectors. This is actually worse than capitalism, Wark argues, because the information vector can render everything on the planet a resource.

So what does all this mean for geoengineering? If capitalism is focused on vectoral control and ineffective when it comes to ensuring the material conditions of its own existence, solar geoengineering would be done by states or not at all. As for carbon removal, the question is this: If zombified neoliberal capitalism isn't going to build up CCS and carbon removal in order to save itself from planetary crisis, who's going to do it?

We, the workers and voters, will have to decide to force the removal of carbon from the atmosphere. And we should—those of us living in the global North, in particular. A whole host of commonly accepted moral principles align with carbon removal: "clean up your own mess," "the polluter pays," the "precautionary principle," and others. Moreover, doing carbon removal in a socially just and environmentally rigorous manner is not just morally desirable—*it is actually a precondition for emissions going net negative*.

There are basically two levels to carbon removal, as I see it. Level 1 involves niche, boutique, aesthetic, or symbolic removals. This is the biochar at your farmer's market, the wool beanie grown with regeneratively grazed sheep, the shoes made with recycled carbon, water carbonated by Coca-Cola with carbon captured directly from the air. It is cool. Advocates see it as the first step toward reaching Level 2. You don't want to knock its fragile emergence, because it's important for generating momentum and raising awareness of carbon removal. But it's geophysically impossible that it will "solve" climate change.

Level 2 is the gigaton-scale removals that could actually lower greenhouse gas concentrations. Call it "climate significant." It's waste cleanup; pollution disposal.

How does one get from Level 1 to Level 2? Some people think it will naturally happen, just as cleantech—renewable energy—"naturally" becomes cheaper and scales. But unlike cleantech, Level 2 is a cleanup operation; in general, these scales of storage and disposal don't generate usable products. I asked Noah Deich, executive director of the nonprofit Carbon180, about these middle-range pathways from demonstration to disposal scales, because his organization has done significant work articulating policy proposals for carbon removal. In the near term, Deich sees a threefold approach, or a "stool with three legs." One is moonshot research and development across the technology and land sectors. The second is supporting entrepreneurs to bring promising ideas to market.

Lastly, he notes, “we need to change policy so that there’s sufficient funding for the research and development, but there are also large-scale markets, so that those entrepreneurs and those land managers can access those markets at a meaningful scale.” The near-term actions he identifies include engagement of universities in research and development, starting up an incubator for carbon tech, and policy work such as implementation of tax credits for CCS and the inclusion of carbon farming in the US farm bill.

When I remarked that the middle time frame seemed fuzzy, Deich replied, “The middle part will remain fuzzy, because I think it’s iterative.” You get started with technology in existing markets, which creates jobs and investment opportunities, he says. Success begets policy support, whether it be government or corporate, which begets more markets, and it becomes a reinforcing cycle that snowballs. “If we’re able to create incentives for taking that carbon out of the air, I think it’s reasonable that we’ll be able to ratchet up those incentives and build that broad political coalition that’s both durable and meaningful to do this at large scale.”

Yet I am less and less convinced that there is a clear route from Level 1 to Level 2, nor that the first would naturally progress to the next. Level 1 is what our current set of policies and incentives can accomplish, with a lot of work from think tanks, NGOs, philanthropists, and the like. Level 2 requires a massive transformation: economic, political, cultural. It implies that we decide to treat carbon dioxide as a waste product and dedicate a significant portion of GDP to cleaning it up, at the least. It would require profound state regulation—the same sort that’s needed for strong mitigation, and then some.

There is sometimes a hope among environmentalists and social justice advocates that confronting climate change will itself bring about social transformation—that it will flip us into a new narrative that could take on the climate pollution challenge. As cultural theorist Claire Colebrook writes,

> From Naomi Klein’s claim that climate change is the opportunity finally to triumph over capitalism, to the environmental humanities movement that spurns decades of “textualist” theory in order to regain nature and life, to wise geo-engineers who operate from the imperative that if we are to survive we must act immediately and unilaterally, the end of man has generated a thousand tiny industries of new dawns.[14]

However, I think there are plenty of scenarios where we deal with climate change in a middling way that preserves the existing unequal arrangements, leaving us not with a new dawn, but with a long and torturous afternoon. Replacing our current liquid fuels with synthetic, lower-carbon fuels produced with direct air capture and enhanced oil recovery would be one version. But those dawnless scenarios are not necessarily geoengineering scenarios, and vice versa. There are both horrifying and mildly likeable scenarios for how carbon removal might be accomplished. The horrifying ones are easy to conjure to mind, while the likable ones stretch the imagination. It would be easy to tag best-case carbon removal scenarios as utopias—even though they would actually be worlds that have failed to mitigate in time, representing at best a muddling through. That's where we're at: even muddling through looks like an amazing social feat, an orchestration so elaborate and requiring so much luck that people may find it a fantastic, utopian dream.

We can maximize our chances of muddling through by engaging proactively with both carbon removal and solar geoengineering. However, binary thinking about climate engineering has made it difficult for progressives to create a dialogue about how engaging with these emerging approaches might be done. Climate engineering has been stuck in the realm of "technology," rather than understood as a variety of practices that include people in various relationships with nature and each other. To free ourselves of these binaries and imagine a different kind of strategy-led engagement, it's valuable to articulate a best-case scenario for how these practices could unfold.

Rigid binaries leave climate engineering in the hands of elites

There's an abyss in contemporary thinking about the role of industrial technology in coping with climate change.

On one side of this abyss are people who appraise the potential of technology optimistically, but fail to articulate any real historical awareness of how technology has developed in and through contexts that are often exploitative, unequal, and even violent.

On the other side of the abyss are thinkers who, on the contrary, have a deep understanding of colonialism, imperialism, and the historical evolution of capitalism, but dismiss technology as a useful part of responding to climate change.

This cleavage leaves little room for critical discussion of how technologies might be used to further climate justice. It makes it impossible to imagine, for example, democratically controlled industrial technology that doesn't exist to "conquer" nature. Today, most left thinking has abandoned the "streak of admiration for the productive forces as the instruments of a conquest of nature that will ultimately usher in communist affluence for everyone," as human ecologist Andreas Malm has observed.[15] But this abandonment did not immediately lead to a coherent articulation of a view of technology that is collective or cooperative, or that works with nature.

I am not the first to observe this. A number of calls have emerged recently for the left to think differently about industrial technology. Geographer Matthew Huber, for one, suggests that "Marx believed that there is something inherently emancipatory about large-scale industrialization, and ecosocialists need not be so quick to dismiss this possibility." He asks, "What if the phrase 'development of the productive forces' was not simply equated with the expansion of dirty industrial production based on coal, oil, and gas and instead represented the full development of industrial energy systems based on cleaner and renewable fuels?"[16] Sociologist Jesse Goldstein, in *Planetary Improvement*, his critical ethnographic analysis of cleantech, observes that "the sociotechnical capacity is out there to transform the world in any number of ways," but realizing emancipatory visions will require "killing the investor" in our minds, "thereby liberating our imaginations, our sciences, and our technologies from the narrowing logic of capital."[17]

Others calls to embrace industrial technology are more strident. Science journalist Leigh Phillips, in his book *Austerity Ecology and the Collapse-Porn Addicts: A Defence of Growth, Progress, Industry, and Stuff*, derides the left's small-is-beautiful, local-retreat tendencies, pointing out that the left was not always this way:

> Historically, when we criticised the failings of the market, the left had no particular quarrel with industry, let alone science, technology, or medicine. We celebrated modernity. Rather,

> our demand had always been that the fruits of civilization should be extended to *all* of humanity. When did we turn away from the idea that capitalism was the problem, and begin to believe that it was modernity instead, or even the advent of mankind itself, that was the problem?[18]

Phillips's book attempts to answer that question by arguing that austerity ecology is an incarnation of a "very old, dark and Malthusian set of ideas that the left historically did battle with." Phillips sees austerity and degrowth as "mathematically and socially identical." To solve the global biocrisis, more is needed: more growth, progress, industry, and civilization. He asserts that "it will require significant ingenuity to engineer a reverse of the processes we have inadvertently set in motion, likely even some way to produce a carbon-negative economy for a period," with hundreds of innovations that will come from the most advanced research laboratories and factories. "By turning its back on the possibility of such technologies, on the very idea of progress, green anti-modernism *actually commits us to catastrophic climate change*." The conclusion is that retreat is not an option; we must accelerate modernity. In some kind of company with this book is Nick Srnicek and Alex Williams's *Inventing the Future: Postcapitalism and a World without Work*. Srnicek and Williams reject the localism of "folk politics" and call for repurposing technologies, pointing out that it's not just about seizing the means of production, but inventing *new* means of production.[19]

Xenofeminism, as articulated in the *Xenofeminist Manifesto* by the collective Laboria Cuboniks, also seeks to "strategically deploy existing technologies to re-engineer the world." They ask, "Why is there so little explicit, organized effort to repurpose technologies for progressive gender political ends?" The real emancipatory potential of tech, they claim, is unrealized:

> The excess of modesty in feminist agendas of recent decades is not proportionate to the monstrous complexity of our reality, a reality cross-hatched with fibre-optic cables, radio and microwaves, oil and gas pipelines, aerial and shipping routes, and the unrelenting, simultaneous execution of millions of communication protocols with every passing millisecond. Systematic thinking and structural analysis have largely fallen by the wayside in favour of admirable, but insufficient struggles, bound to fixed localities and fragmented insurrections.[20]

Again, there is a call for a wider scale of analysis and practice than local efforts or folk politics can allow for. The *Xenofeminist Manifesto* further

asserts that "suggestions to pull the lever on the emergency brake of embedded velocities, the call to slow down and scale back, is a possibility available only to the few—a violent particularity of exclusivity—ultimately entailing catastrophe for the many."

While these currents are swirling on the radical left, they haven't seeped into the environmental mainstream. There, the conception of an industrial technology that works with nature is limited to solar panels and wind turbines (as long as they are not in anyone's backyard). Otherwise, industrial technology is still seen as that of the dark satanic mills—and certainly, there are plenty of extractive operations around the globe that reinforce this view. Technology and capitalism remain conflated (and the heavy government subsidies received by many transformative technologies are elided from view). So when it comes to geoengineering, many environmentalists have adopted a simple refrain: "We don't need geoengineering, we need *x*." This is a familiar formula, where *x* may be sustainable, ecological agriculture. Or system transformation. Or degrowth. Geoengineering serves as a foil for the beautiful *x*, the blossoming future we *really* want.

Let's look more closely around how these binaries are articulated, and where they originate. One formulation of the binary is to view geoengineering as conflicting with real, transformative change. This is a compelling structure of thought because it focuses on changes that advocates *actually want*. The ETC Group, a civil society organization critical of the ways many emerging technologies are conceived and wielded, warns against geoengineering as a "perfect excuse": "Geoengineering offers governments an option other than reducing emissions and protecting biodiversity."[21] Journalist and activist Naomi Klein declares that "the fact that geoengineering is being treated so seriously should underline the urgent need for a real plan A—one based on emission reduction, however economically radical it must be."[22]

Advocates of geoengineering research, on the other hand, tend to believe that mitigation will not be enough to stave off the worst of climate change. One counterargument to the no-plan-but-mitigation position is posed by Harvard solar geoengineering researchers David Keith and Josh Horton:

> At the risk of oversimplification, this line of argument essentially involves rich-country commentators criticizing solar geoengineering in an effort to shore up mitigation as their priority domestic climate policy, while ignoring the potentially huge distributional advantages SRM [solar radiation management] might confer on the world's poorest in the global South. Their deeper motives vary, from a sense of moral indignation over shirking (Hamilton) to neo-Luddism (ETC Group) to anti-corporate ideology (Klein) and beyond. Whatever the reasons, the resulting admonition not to research SRM for fear of its policy implications for industrialized countries, at the expense of possibly enormous welfare gains in developing countries, is ethically disturbing in a global moral context.[23]

Retorts to *this* counterargument have included assertions that research advocates are being insincere about their concerns for vulnerable people, or limited in their thinking. Environmental policy scholars Jane Flegal and Aarti Gupta, for example, point out that the "performative power and political implications of specific expert visions of equity, evoked as a rationale to undertake solar geoengineering research, require continued scrutiny"—in part because these expert visions are filtered through a technological frame where equity is understood only narrowly.[24] Moreover, philosopher and activist Kyle Whyte observes that "the argument that geoengineering is actually intended to sort of save or support indigenous people is actually hard to maintain because it's not temperature rise or unpredictable precipitation that are really the problems."[25] Rather, colonialism and global inequality are at the heart of climate change—so if you care about the poorest in the global South, shouldn't those be first and foremost in the discussion?

I agree wholeheartedly with the critiques offered by Whyte, Flegal, Gupta, and others of the solar geoengineering research enterprise. Yet, to me, it is presumptuous to entirely cross off an idea that could, in a future scenario with runaway climate change, alleviate much suffering in places with less capacity to adapt to changing conditions. Systemic change is absolutely necessary. But geoengineering does not have to substitute for transformative change—in fact, to work well, geoengineering *requires* systemic change, because *responsible solar geoengineering requires carbon removal, which requires renewable energy*. This scale-up of renewables and carbon removal is only accomplishable with massive social and political transformation. The best-case solar geoengineering scenario is only achievable with dramatic social change. At the same time, critics rightfully worry that fossil fuel actors and other elites will use solar geoengineering to forestall social transformation, and the same concern applies to carbon

removal. Yet at this point in time, a blanket rejection of carbon removal, in particular, comes off as an aesthetic luxury.

At the roots of this binary between geoengineering and social transformation, I think, are contemporary struggles around agriculture and food sovereignty. Contemporary agriculture is riddled with binary constructions: there's holistic agroecology versus reductionist and mechanistic industrial agriculture; resilient agroecology versus techno-fix drought-resistant crop breeding. Geoengineering gets mapped onto these preexisting binaries, leading to the impression that geoengineering represents one distinct set of options, and agroecological transformation another. It is the mindsets, values, cultures, and systems behind these practices that agroecology advocates perceive to be in conflict. "We need regenerative farming, not geoengineering," argues teacher and activist Charles Eisenstein in a 2015 *Guardian* op-ed.[26] The ETC Group, for its part, opposes geoengineering as a false solution to climate change, along with proprietary climate-ready crops, and supports peasant-led agroecological responses to the climate crisis.[27] Environmental NGO Biofuelwatch calls climate engineering techniques like bioenergy with CCS a "distraction of attention away from genuine and credible ways of sequestering carbon: agroecology and ecosystem regeneration."[28]

One more binary merits discussion here—one that lies *within* carbon removal practices themselves. Scientific and policy reports categorize these practices as *biological* (or natural) climate solutions, on one hand, and *engineered* solutions, on the other. This is reasonable to some degree: carbon can be sequestered either by growing more things (the focus of Part I of this book), or by burying it geologically (discussed in Part II of this book). In climate policy discourse, though, the divide between the industrial and the biological is playing out within carbon removal itself, with one side often (but not always) privileged over another. At the brink of desperation, activist groups like the Sunrise Movement, The Climate Mobilization and Extinction Rebellion are beginning to engage with demands for carbon drawdown. But many climate justice groups are ambiguous about how the drawdown can be achieved, and there is often a cognitive gap between the demand for drawdown and the scale of industrial activity required to accomplish it.

These overlapping binaries—geoengineering versus real change, geoengineering versus agroecology—obscure the reality that there is a spectrum of ways of doing, enacting, practicing, deploying, or implementing climate intervention. The implementation does not inhere in the technology. Sticking rigidly to these binaries keeps us from seeing possible futures: it gives the terrain for shaping climate engineering over to the few.

Climate intervention as practice

Climate engineering is not a monolithic "technology," but a variety of *practices* (or activities), and actors have some level of choice about *how* they will practice it. Jack Stilgoe, in *Experiment Earth*, suggests that we need to view geoengineering not as a noun but as a verb: "Viewed as a set of technologies, geo-engineering resembles no more than a mixed bag of half-baked schemes. If we take literally the meaning of 'geoengineering' as a present participle, it becomes a project, a work-in-progress." Stilgoe suggests that viewed this way, geoengineering is a form of governance.[29] Yet often, climate engineering is still viewed as a "thing," an artifact that comes out of this box of emerging technologies, alongside genetics, robotics, information technology, and nanotechnology. In some very important ways, climate geoengineering is not like these other emerging technologies.

Emerging technologies are sometimes imagined to spur new long waves of innovation, or "Kondratiev waves," after the economist who theorized them. First there were textiles during the Industrial Revolution, followed by steam and rail, and then electricity, and then automobiles and the petroleum age, and later information technology; some new transformative innovation comes along every forty to sixty years. This theory isn't a particularly fashionable one in mainstream economics right now, but I mention it here because it helps illustrate an interesting point: geoengineering is never going to be like those other emerging technologies, all of which played transformative roles in economies. Instead, carbon removal is likely to be analogous to waste control: a massive industry, but not a transformative one. Solar geoengineering, in particular, is ameliorative and not generative;

that is, it doesn't generate new wealth. Its growth is necessarily limited, and the number of actors that would be needed for its realization is also limited. What would be their motivation to engage? Researchers can gain individual glory and social capital, maybe, but it is difficult to imagine solar geoengineering being accomplished through an investment/shareholder corporate model. When it comes to real-world benefits, solar geoengineering is so broad, crude, risky, and low profit that it is best viewed as a global public project. The benefits of carbon removal would also be a global public good, though potentially one with damaging effects in particular places, depending on policy design. In short, it's easier to envisage climate engineering as undertaken for the benefit of the many.

The point here is that solar geoengineering is not actually "a technology"—indeed, most of these socio-technical systems aren't. The planes and nozzles, and the software that drives and creates solar geoengineering would be technologies, as are the computer models that indicate it would cool the planet. But while solar geoengineering *relies* on such technology, it would be more than that. When we put it in the "technology" box, it becomes the domain of technology experts, and we fail to see what else it is; the social life of the intervention is obscured.

If geoengineering is not simply an emerging technology, what is it? Let's consider three alternative frames: development interventions, humanitarian interventions, and infrastructure. None of these is sufficient on its own to understand geoengineering, but each of them can illuminate something about what geoengineering could be.

Development-speak is filled with the language of intervention, from community-level health or nutrition interventions to macro-level economic interventions. Climate-related development interventions have included things like education in climate-smart agricultural practices for farmers, or the institution of clean cook-stoves. Interventions like these are usually designed to have multiple social and climate benefits. These programs are also monitored and evaluated, an aspect that makes them a useful analog to solar geoengineering. For solar geoengineering, too, would require implementation and management across years and years, and continual monitoring and evaluation. When it comes to carbon removal, there are some ways in which it is already conceived of as a development intervention—something that is apparent, for instance, in community forestry or biochar projects.

“Intervention” also comes up in humanitarian work, where it implies intervening in some disastrous situation, either through military force or humanitarian aid and relief, and often in an international or nongovernment partnership. There’s generally no direct profit motive, although private contractors do profit from humanitarian work. Humanitarian interventions constitute a relevant parallel because of the emergency rationale; like for solar geoengineering, the interventions aim to “save” or “stabilize” something. Humanitarian interventions tend to borrow heavily from military language, describing their projects in terms of missions or deployment. The same is true for the language typically used to speak about solar geoengineering.

Much of the earliest work on geoengineering used the term “climate intervention.” Take, for instance, the 2010 “Asilomar International Conference on Climate Intervention Technologies”; the 2015 National Academies reports on climate intervention also adopted this term. It is used synonymously with both “climate engineering” and “geoengineering.” So why isn’t “intervention” a go-to frame for understanding climate engineering? One reason is that intervention in the development or humanitarian context focuses on the action; but with geoengineering, focusing on the action seems “premature.” Researchers are careful to specify that right now we’re only talking about research, and not thinking about deployment. There’s a carefully constructed gap: On one side is an idealized world where we can run models, and where solar geoengineering is abstract, and therefore safe. On the other side is the world of imagined deployment, which leads one down the path of imagining *particular* deployment scenarios; using analogies like intervention pushes the conversation from research talk into deployment talk. Another reason not to employ these analogues concerns optics: the “humanitarian intervention” comparison sounds like greenwashing, an Orwellian euphemism. I don’t necessarily find these terms euphemistic, though, since neither the term “development” nor “humanitarian” connotes *goodness* to me. Rather, they refer to specific goals and projects. The development project has worked out quite terribly in many places, extending Western colonialism, trapping poor nations in debt, and transforming communal social relations into exploitative ones. Similarly, when it comes to humanitarian intervention, we’ve seen plenty of disastrous results. The fact that many of these social interventions have gone so terribly wrong, in fact, is precisely the reason

why it is important to think about geoengineering with reference to these examples.

While part of climate engineering resembles a programmatic intervention—something constructed, through time, with specific goals and management superstructure—another part of is more like infrastructure—fixed, heavy, material. It is natural to talk about infrastructure when considering carbon dioxide removal, since industrial forms of carbon removal require large-scale pipelines and facilities. Similarly, reforestation and soil carbon sequestration can be seen through the lens of "ecological infrastructure." Solar geoengineering, by contrast, appears more intangible, ethereal. But its infrastructure is simply flexible, and approaches like stratospheric aerosols are reliant on existing fixed infrastructure such as runways, factories, and mines. The moment of infrastructural development is a flash point for contestation; the concrete image, whether it be a diagram or architectural rendering, makes it real enough to fight against. Until the infrastructure is imagined, we're still in the sci-fi fantasy space of floating cities. It's also helpful to think of geoengineering as infrastructure, as environmental humanities scholar Anne Pasek points out in her in-depth analysis, because doing so evokes the care and maintenance required.[30]

By thinking of geoengineering as infrastructure, we position ourselves to heed the lessons of past megaprojects. The most familiar megaprojects are multibillion-dollar infrastructure projects: the Channel Tunnel, the Øresund Bridge, the Three Gorges Dam, the Hong Kong International Airport, and so on. Megaprojects can involve infrastructure (dams, ports, and railroads); extraction (minerals, fossil fuels); production (fighter aircraft, chemical plants, and manufacturing parks); and consumption (tourist installations, malls, and theme parks), notes Bent Flyvbjerg, a megaprojects expert. He writes that megaprojects are part of a remarkably coherent story, what sociologist Zygmunt Bauman has called the "Great War of Independence from Space." They imply mobility, liberation. He talks about the end of geography, the death of distance, and so on.[31] Perhaps you remember this zeitgeist from the early 2000s, when the internet was new and transformative, before we knew it would give us so many cat videos and listicles and trolls. When "globalization" was still a buzzword, before the financial crisis and the failed interventions in Iraq and Afghanistan. Critics of geoengineering tend to locate the psychological roots of climate engineering in postwar, big science techno-optimism, in

1950s thinking. But it is equally useful to regard it as a phenomenon born of the early 2000s, a more globalist moment.

The paradox of megaprojects, Flyvbjerg writes, is that even as more and larger infrastructure projects are proposed and built, they evidence strikingly poor performance records in terms of economy, environment, and public support. Geographers Ben Marsh and Janet Jones point out, however, that when you take into account symbolism, this is only an *apparent* paradox—economic performance is not the only measure of success, as megaprojects are planned and executed for a symbolic value that can be more stunning than their fiscal value.[32] Infrastructure inscribes cultural messages in the landscape; it expresses both authorship and authority. Mega-engineering projects are hyperlegible; scale becomes a design factor. And so, Marsh and Jones observe, while power is the "foremost statement" of large landscape projects, the actual messages are diverse, ranging from abundance (the Hanging Gardens of Babylon) to security (levees on floodplains). But if infrastructure is about messaging, it begs the question: Could climate engineering projects be more effective as a symbolic strategy than as a material one?

The shortcomings of large infrastructure projects have generated suspicion about megaprojects, suspicion which may be transferred to solar geoengineering. Flyvbjerg points out that the documents of megaproject preparation—cost–benefit analyses, financial analyses, impact statements—are called into question and denounced more often than analyses in any other professional field. It's common to have cost overruns of 50 to 100 percent or more, and demand forecasts that are wrong by 20 to 70 percent.[33] As Flyvbjerg writes, the key problem is lack of accountability, not lack of technical skills or data. Forecasts are manipulated, special interest groups promote projects at no cost or risk to themselves, contractors underestimate costs and risks—meaning the real costs and risks don't surface until construction is underway. This happens drastically in defense contracts, for example, with taxpayers footing the bill. "Appraisal optimism" is a generous way to put all of this, and the collective experience with megaprojects is a cautionary tale for climate engineering.

But solar geoengineering has another perceived relationship to infrastructure: rightly or wrongly, it is seen as a blanket infrastructure *preserver*. There are quite reasonable concerns that solar geoengineering is a way to avoid changing this other $13 trillion infrastructure of fossil fuels,

implying a workaround for the phaseout of new fossil fuel plants "prematurely," and saving assets from being stranded. But infrastructure always changes; as science historian David Nye writes, "Even the largest and most successful technological systems eventually lose momentum."[34] He offers examples from the coal distribution infrastructure of the last century: abandoned coal yards, wagons, bins, and chutes. Think of the rapid build-out of communications infrastructure, or of the structures left behind in the wake of the exodus from agriculture. History shows infrastructure's impermanence and offers lessons on how people in particular places react to the changes.

Understanding geoengineering as a program, practice, project, intervention, infrastructure, and so on might make the concept seem sprawling. But consider what environmental scientist Brad Allenby writes about jet technology: a traditional life cycle analysis counts the use phase of the jet itself, but really, the jet enabled a global tourism industry to spring up, which, as Allenby points out, has probably had more impact on the biosphere than anything since European colonialism—in terms of knitting together population centers but also creating new disease and invasive species vectors. "So, should these profoundly systemic effects be considered as one contemplates design of a jet aircraft?" Allenby asks.[35] The complexity becomes staggering. Nevertheless, a systemic perspective is necessary. We need to understand the indirect effects of interventions, the parts of the system that behave differently at different scales, and so on. We don't currently have the institutions, training, and methods to adequately look at something like climate engineering from a systemic perspective. Even in the halls of the world's most vaunted universities, the discussion and framing of both solar geoengineering and carbon removal is extraordinarily thin, stripping out the social complexity.

Looking at the history of megaprojects and failed interventions, the question looms: How do we prevent failed attempts at geoengineering? Solar geoengineering isn't a regular project: the damage of an aborted or poorly executed project isn't measured in costs or missed opportunities to invest in other things, but in ecological dangers. In fact, the fiscal cost is the least significant aspect of the failure. The worst-case scenario here might not even be extreme climate change, or that solar geoengineering is done, but that solar geoengineering is attempted poorly.

In short, rather than simply being emerging technologies, both solar geoengineering and carbon removal would be practices that have aspects of infrastructure and social intervention. They must be wrested from the realm of technology—where only experts are permitted—and seen through the prism of projects, programs, and practices if civil society is going to attempt to shape them in a meaningfully democratic way.

What would a better-case geoengineering look like?

Swift and deep decarbonization is the best-case climate future. But again, the specter rears its head that this won't happen in time to avoid extreme climate impacts. There's a genuine possibility that only clear and significant climate impacts will motivate real action, and by then, a significant level of warming will be locked in and looming.

Many forms of geoengineering may be dangerous or unworkable. Even the basic idea of drawing down greenhouse gas concentrations has its unknowns. When carbon dioxide is emitted, about a quarter goes into the oceans, about a quarter of it is stored in ecosystems, and about half of it remains in the atmosphere. So removing 100 Gt from the earth system would roughly mean reducing the total amount in the atmosphere by only 50 Gt. If carbon removal reduced carbon concentrations in the atmosphere, CO_2 in the oceans would gradually transfer back to the atmosphere, a flow that is complicated to model because of how the layers of the ocean mix. Carbon cycle feedbacks could reduce the effectiveness of carbon removal, or perhaps enhance it.

Yet the possibility of climate catastrophe makes thinking through the best-case use of all these approaches a valuable thought experiment. For if their best-case use, under close examination, is unattainable, perhaps the idea had better be removed from discussion—which may not be an easy feat.

Is there a synthesis to be had between geoengineering and sustainable agriculture (and earth care)—a better "geoengineering"? Or, perhaps not a collapsing or synthesis of these two practices, but a new term and framework of understanding to be created? Indeed, "climate restoration" advocates and other groups may create the ground for this. This book

profiles a handful of people who are articulating visions that transcend this binary. In the following chapters, we'll explore possible contours of a world during and after geoengineering, through the voices of some of the scientists, entrepreneurs, and activists that could have a role in shaping this world.

Here's an after-geoengineering test for geoengineering proposals: Is this proposed program or project likely to produce a livable world 200 years from now? By making a best-case scenario vivid, it becomes easier to grasp the magnitude of the challenge, and to see how it runs through many aspects of everyday life, in ways viewing geoengineering simply as a "technology" may not.

So often, climate futures are described in terms of mathematical pathways or scenarios, behind which are traditions of men gaming out possible futures. In this book, I've used fiction to do what nonfiction writing cannot do as well: to make the future less empty, to populate it with embodied lives and emotions. For it is *people*, with bodies and lives, who have to experience climate change; climate futures aren't just about geopolitical and temperature events. While there are many reasons for climate inaction, one of them is that climate change has been coded as an issue of "science" or "politics," of serious and hard stuff, with the human content and emotions separated out. This division performs, yet again, the master nature/culture binary that this book seeks to do away with. Fiction is one way to bring back in that which has been parceled out of the climate change conversation; this book's hybrid form is meant to create a synthesis, to bridge that binary. Although such hybrids can seem like strange creatures, the aim is to invite the reader into alternative imaginations of the future, for small fractions of this book, and to experience something different.

This book is about the future—including scenes that speculate about the end of the century—but that future starts right now. The actions we take during the next decade will drastically shape what kind of world our descendants dwell in.