CLIMATE'S BIG PICTURE

Nine Aspects of the Crisis

WILLIAM H. CALVIN, PH.D.

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Updated versions of this draft ms can be found at
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Illustration List

(All are optional; text does not refer to them.)

Climate's Big Picture

Climate action now needs the medical mindset

WILLIAM H. CALVIN [1]

The focus will be on 21st-century surges in global *weirding* now occurring atop the creep in global *warming*. Future climate change is not merely a matter of more hot summers and more weeks of stay-indoors wildfire smoke in future decades. Indeed, extreme weather surge-and-stay may collapse our civilization before the creep up in temperature does.

When global overheating paused between 2001 and 2013—what we hope to achieve with our net zero strategy—extreme weather did not pause with it. Instead, it surged, including two *mega* heatwaves that killed 126,000 Europeans during the *global* overheating pause.

We need a new climate strategy. Forget those end-of-the-century projections that assume smooth change; they never were more than an argument that "It will be at least this bad, and that's if there are no

Figure 1. Death Valley, California USA

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surprises along the way." So far, the 21st-century has been full of unpleasant surprises. Climate instabilities will likely shorten the time remaining before an inattentive civilization collapses — or, at least, becomes sufficiently disorganized that climate repairs are abandoned.

Too late may arrive even before a *tipping point* is reached. That is because of the lead times for doing something that is sufficiently *big*— and also *quick* enough to head off a profound economic collapse. That 'something' must also be *surefire on the first try*, as there will likely be no time for a second try before we have a broken civilization incapable of saving its citizens.

Widespread institutional collapse, in the manner of failed states, is likely to be followed by a messy population crash featuring famines, resource wars, pandemics, and genocides. That is what collapse looks like. Pervasive gang warfare and protection rackets are just the start.

"Do we really need to be talking about that, already?" Yes, and it is because of fifty years of denial and delay. The new 21st-century climate history has changed in sustained steps, not just gradual-ly. There were five extreme weather surge-and-stays (steps in numbers or intensity to triple or more) between 2002 and 2010. Unlike storm surges, none have retreated.

Though more extreme weather was expected with overheating, the sudden steps were a surprise. The winds discovered new modes of operation, analogous to when the failure of the trade winds flips us from La Niña conditions into the El Niño mode. Anything that sends the rain elsewhere is likely to promote both droughts and wildfires— and also unleash flash floods in new places.

Blocking highs spell trouble. They stall the eastward drift of the polar jet stream's footprint and squeeze those loopy meanders to prolong heat waves or make hurricanes stall for days. The tight hairpin turns that reverse the jet's direction also promote high winds, hailstorms, flash floods, and fire weather.

We currently have no means of foreseeing the next big surge-and-stay. We do not understand the atmosphere's fluid mechanics well enough to do better. Chaos theory being what it is, we may never.

Missing from the public discourse about climate threats is the profess-ional engineer's focus on analyzing failure modes, which is how they determine what safety margins are needed to avoid structural collapse. Such failure mode considerations are not just important for our society's planners to think about; they would also allow experts to speak to the public and legislators in more familiar terms than those fractional degrees of global overheating, which allow many readers to put off serious climate action.

We medical-school professors are likely the largest occupational group that teaches about collapse. And some of the distinctions we make would be useful in the public discourse about climate action. Preventative actions (say, diets and vaccines) differ from treatments and they in turn differ from actions that merely "buy time" by relieving symptoms of a progressive disease. Limiting intake (a diet) differs from cleanup of an accumulation (dialysis, draining an abscess, liposuction). Halting progression (as in net zero emissions) differs from repair; it in turn differs from restoration and redesigning for next time—or creating regulating feedback to enforce stability.

Stable is not just a matter of a monitor curve that somehow stays flat. Something that currently appears unchanging may prove fragile if pushed. *Stabilizing*, however, implies bracing to prevent wobble that is threatening collapse. (Think of outriggers or the deep keel on a sailboat.) In medicine we speak of "stabilizing the patient." This involves increasing blood volume via a saline drip and adding drugs that elevate blood pressure. Both are aimed at moving back, in advance of need, from the danger zone for a slippery slope. Something similar is now needed for climate.

How are we doing? Currently, more than 80 percent of the world's energy production still comes from fossil fuels.

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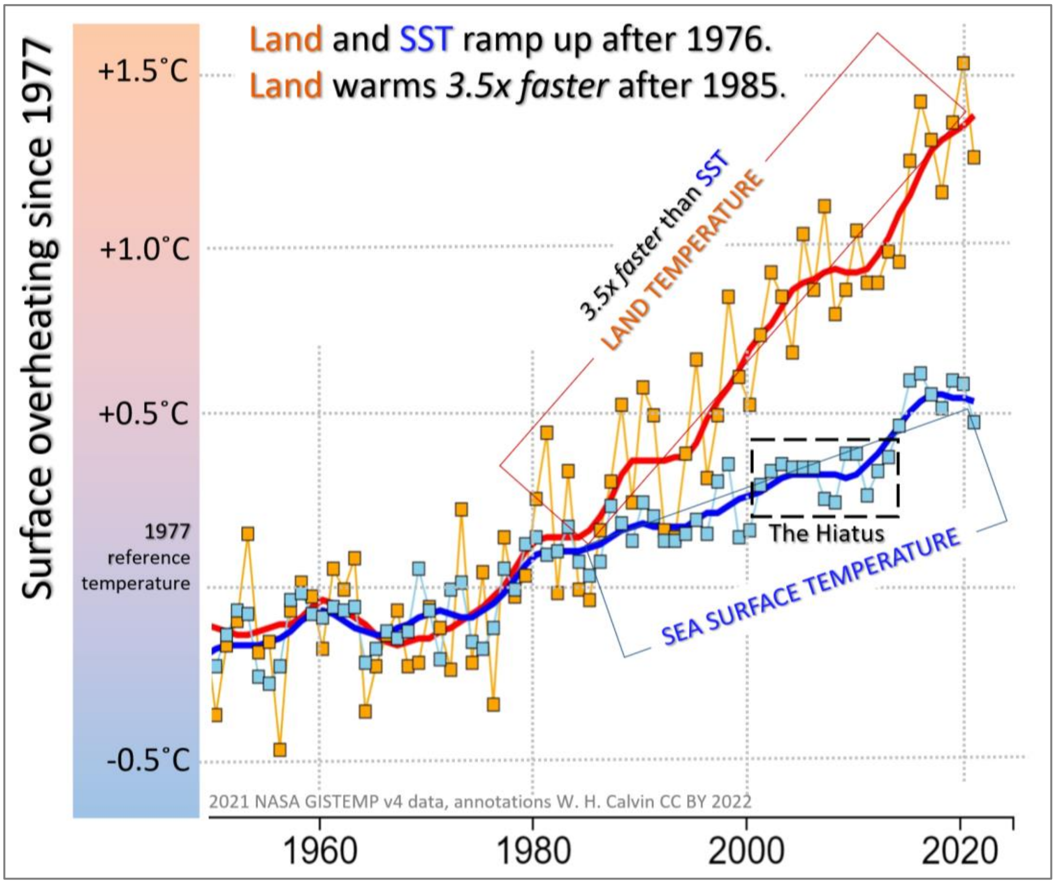

Figure 2. The history of surface temperature since 1950. Sea surface temperatures (SST) have been slid up about 9°C to overlap land temperatures in 1977. Though the concentration of carbon dioxide was steadily rising, something compensated to keep global surface temperatures from rising between 1950 and 1976. After 1976, surface temperature ramped up in parallel on both land and ocean. Land and SST track one another from 1900 until the mid-1980s when the continents and the Arctic began warming almost four times faster. Increasing temperature contrast at coastlines tends to rearrange the winds that deliver rain, leading to droughts here and floods there.

There was a 13-year period when, despite rising CO_2 levels, global temperature stayed flat without major volcanic eruptions to blame. Here the squares are *annual* averages; the heavy line is Lowess smoothed over five years, which spreads out sudden transitions that are best judged from the blue SST squares showing the annual average without smoothing.

"Global" (not shown) is the mix of 71% SST, 29% land. SST varies year-to-year less than land; on continents, evaporative cooling varies with that year's drought acreage. Though I understand the 1970s energy budget reasons for talking of a global average temperature, most of us live on continents that are heating up 3-4x faster since 1985. It no longer makes much sense to dilute our chosen temperature index with several parts of slower-rising sea surface temperature, especially when so many people underestimate the climate problem when it is presented as a change of only a fraction of a degree in some future decade. But then surface temps, diluted or not, turn out to be a poor index of climate troubles.

Climate's Big Picture

'Think again' about the climate diagnosis and treatment plan

WILLIAM H. CALVIN[2]

We medical school professors teach our students to "Think again," to regularly reconsider both the patient's diagnosis and the treatment plan. One must repeatedly search for new players and for better treatment combinations.

Such meta-level re-evaluation has not been happening for climate disease, even though the 21st-century has seen the rapid onset of serious climate impacts—some of which seem likely to preempt those long-term projections that we scientists find easier to explain and defend.

Unfortunately, to the public and the legislators they vote for, long-term thinking often allows postponing immediate action. Even such safety issues as seatbelt adoption and the smoke-free workplace took a quarter century before meaningful action was taken. Inaction still characterizes areas with a big stockpile to draw down, such as 1.3 guns per person in the US and the 50% excess carbon dioxide overhead.

The physician's mindset is what I hope to convey here, to assist others in rethinking the treatment plans for our climate crisis. For example, the ocean acidification and climate problems that result from atmospheric accumulation of excess carbon dioxide may not automatically fix a problem once you stop feeding the excess. Once you have a dental abscess, better brushing is unlikely to keep the infection from going systemic and killing you. Long-term generalities may prove insufficient for surviving what happens in the meantime.

So, what is our current mindset regarding the climate threat? Here I am not addressing what the public understands but what our leaders aim to convey to everyone—both the scientific leaders and those political leaders most outspoken about the need for climate action. To oversimplify, they say "Overheating bad. Fossil-fuel emissions are the cause, so zero them." This fifty-year-old mindset, influenced by the 1970s success in reducing smog via catalytic converters, has become an inadequate framing for the 21st-century climate threats. Here I am attempting a reframing.

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Back before surface temperatures began ramping up in 1976, promoting emissions reduction was the logical framing for climate action. Now we are already overheated and must quickly clean up a half-century's annual CO_2 contributions in order to back out of the danger zone. Cleanup, with shade in the meantime, are the climate actions where we have too little leadership—or even regular media coverage.

Emissions reduction, furthermore, was already a good idea for economic (LED lighting requires 80% less power) and environmental reasons (cleaning up urban air pollution). But we also saw a lot of re-branding as one group after another claimed that their focus was also relevant to the climate cause. Some vegetarians claimed relevance to "climate solutions" even though uneaten grass would promptly rot, turning back into CO_2.

Most of this was not greenwashing or publicity-seeking; people were eager to contribute what they could to solving climate, putting their own knowledge to work. Even if something would amount to less than one percent of the climate action need, it was still claimed to be a "climate solution" on the "Every little bit counts" principle endorsed by their leaders.

Figure 3. Overclaiming.

Some "climate solutions," however, are only relevant to what might have helped *prevent* the present climate crisis. That is because the need for cleanup-sized actions grew so fast. We now need to *clean up* the 50-year accumulation created while emissions reduction efforts failed to do the job.

It does not help that the public is being distracted by claims of "climate solutions" that are miniscule, the sort of case that a judge might throw out using the de minimis rule. The FDA has rules restricting overclaiming for medical "solutions" but there are no such rules for climate claims and greenwashing has flourished.

Unfortunately, some of the major players have turned out to be minor players— even the most obvious scheme for cleaning up the excess carbon dioxide, planting a trillion trees to store some of the CO_2 excess in wood. How much does that reduce the overheating? Three percent max, and only by the end of the 21st century. It is the same for biochar.

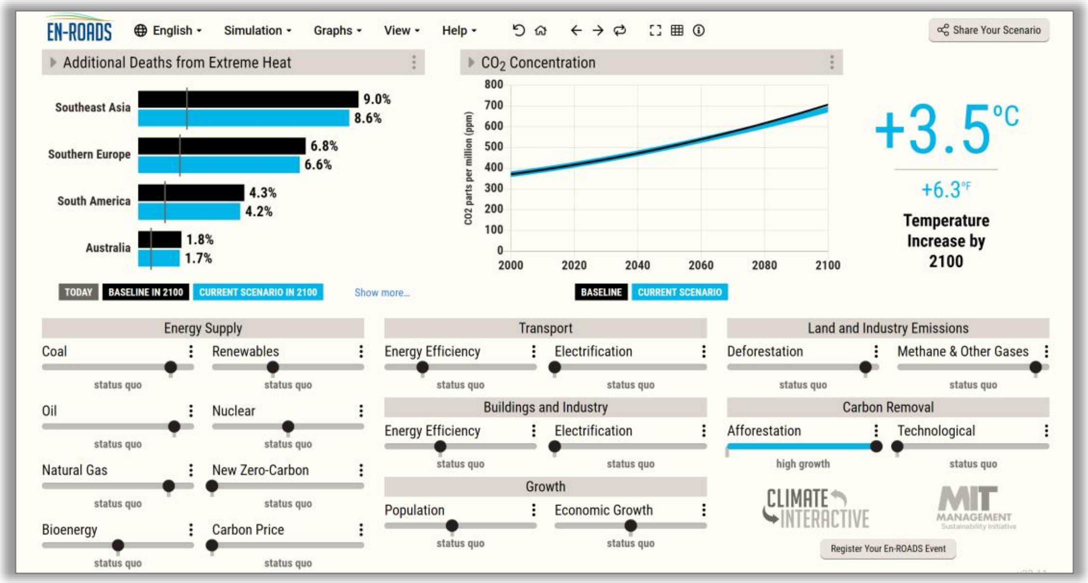

Figure 4. *The Three Percent Solution:* Planting a trillion trees only reduces the end-of-century temperature from 3.6°C of overheating to 3.5°C. Source: climateinteractive.org/en-roads/

A caution: the role of emissions reduction is no longer primary but is still useful in a secondary way, once we actually start doing a big cleanup. It has become what, in medical Latin, would be called an *adjuvant*, a supplementary treatment that is ineffective by itself but augments a more effective treatment. The familiar example is chemotherapy following surgical removal of a tumor, one too big to reduce with chemo alone but where chemo is still useful for speeding recovery and getting at the smaller scattered metastases where chemo may suffice. Zero emissions is an adjuvant that will speed up the cooling from a CO_2 cleanup—that is, provided a serious cleanup is in progress. (It is not.)

Indeed, until about 2018, one would have thought that CO_2 cleanup was a taboo topic like shade geoengineering has been treated. The only climate actions ever mentioned were mitigation and adaptation—which would be new words to learn for many legislators. Diet, shade, and cleanup are more widely understood.

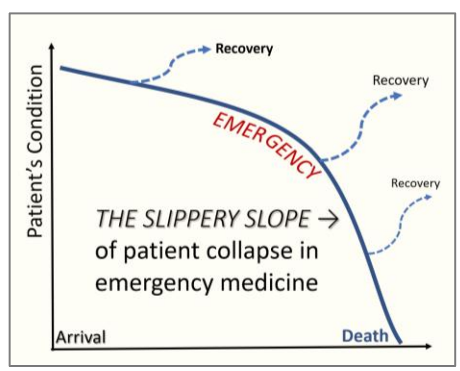

Figure 5. The slippery slope to collapse. In emergency medicine, the emphasis is on getting ahead of the problem *before* it becomes an emergency.

In an emergency, one does not stand around speculating on the ultimate cause of the problem and only doing what once might have headed off the threat. Or so we teach medical students, from the accumulated wisdom (and mistakes) of the 2,500 years since Hippocrates.

Watching the pro's climate thinking developing over the past forty years, I have been searching for comparisons to the mistakes made in the history of medicine via overgeneralization and via the frequent failures to statistically test a promising treatment for actual effectiveness using control groups. Those were the very issues addressed early in the Scientific Revolution (1600s, Shakespeare's generation) by Francis Bacon, English philosopher and statesman for the first Queen Elizabeth. For various reasons, reality testing took another 400 years to creep from scientific thinking into medical thinking.

The modern medical mindset now includes staged strategic thinking, all while keeping an eye on the clock and regularly re-evaluating. Physicians must daily deal with the triple combination of complexity, incomplete understanding, and urgency. Most Ph.D. basic researchers (including me, including climate scientists) get little education for it, nor for the "get ahead of the problem" part of the medical mindset that is so important in emergency medicine, needed to stay hours ahead of possible disease developments before they create a slippery slope toward death.

Emissions reduction is reminiscent of the 1960s medical advice to smokers to "Cut back to one pack per day." Since diets frequently fail, it is surprising that so many leaders have continued to only speak of emissions-rate reductions. Were this "carbon diet" succeeding, the yearly bump-up in carbon dioxide (CO2) accumulation would be declining. Instead, it is now rising 50% more rapidly than in the 1990s.

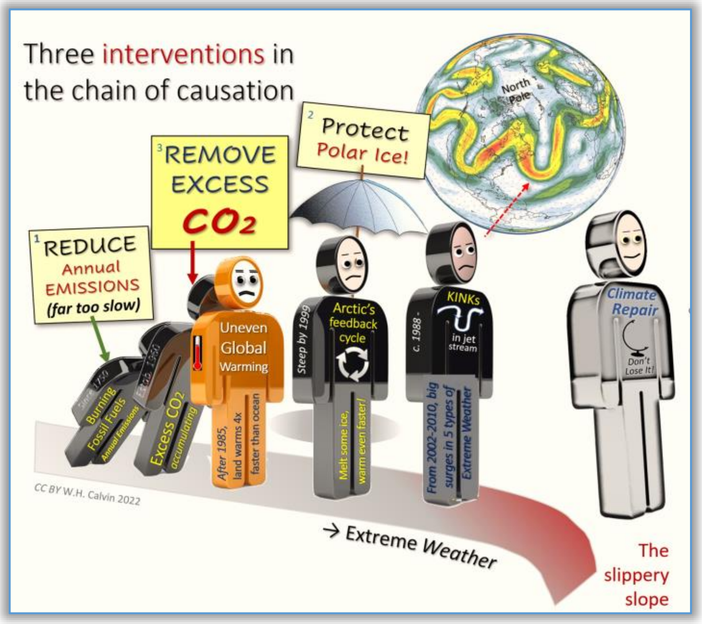

Figure 6. One chain of causation and three ways it might be interrupted.

That is not progress on climate, though seeking emission reductions proved quite useful on economic and some environmental criteria. In medicine today, however logical such a treatment seemed, it would be called an inadequate treatment—perhaps even a harmful failure, such as bleeding and purging were.

Yet today's climate messaging fails to convey the immediate need for stronger medicine. A quote from one of the IPCC scientists: "In 2021 the world spent a total of $755b on reducing emissions. We should probably aim to spend about 1% of that money on carbon removal technologies." Damning with faint praise, indeed. Most climate scientists do not think like our medical students, nor like professional engineers concerned with failure modes.

When scientists got started on the emerging climate problem in the 1960s, the carbon dioxide concentration was 320 parts per million, 14% above the preindustrial high of 280 ppm (also the high during the warmup from the last two ice ages). Today at 420 ppm, there is a 50% excess, halfway to doubling the CO_2 concentration to 560 ppm.

That half-century *accumulation* has now created a climate emergency, the price of those decades of delay and denial. That accumulation, not just our current *rate* of making things worse, is what we must now address.

We have known for decades that net zero emissions, even if achieved, would provide insufficient relief from overheating during the next fifty years. Even after Jared Diamond's book *Collapse* came out in 2005, analyzing how most past civilizations collapsed when hit by big environmental challenges, we did not get a reassessment of 21st-century threats and a major search for better treatment plans, complete with prototypes and field trials to evaluate.

Now we must face up to the possibility of a massive collapse of the global economy and, in many regions, a disorganization similar to the collapse of civilization's institutions, such as education and a judiciary that can enforce contracts and settle disputes. Such things have happened many times before; this is not speculation. "Failed states" are merely the recent examples.

This institutional collapse could occur even before heatwaves start killing millions of people every summer. That threat comes not so much from more fractional degrees of overheating as from the recent surges in extreme weather caused by the existing excess of carbon dioxide overhead.

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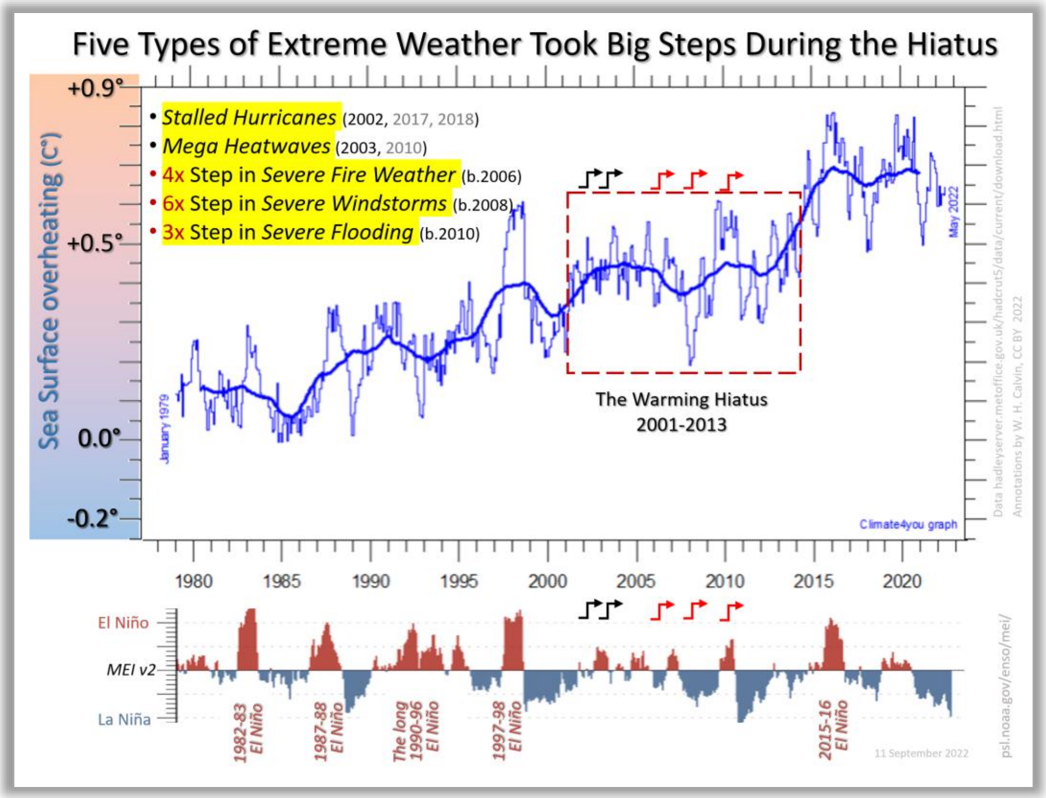

Figure 7. Globally averaged Sea Surface Temperatures (SST), above the pre-1976 baseline; monthly values this time, and (heavy line) their three-year sliding average. SST contributes 71% of the global average surface temperature; the 29% continental contribution exhibits much more variability (droughts reduce evaporative cooling of the surface), so I have chosen SST to identify the hiatus.

Step-arrows mark start times for the Big Five. “Severe” means >$1b damage per US event, per NOAA’s database. “6x” means the average annual rate of >$1b events is now six times the post-1980 baseline’s average rate before the step. My criterion for inclusion in the Big Ones was three times or more increase; the extreme weather runner-up was severe drought at 1.6x.

Lower: The Multivariate ENSO Index Version 2 shows the lack of a big El Niño during the hiatus.

Climate's Big Picture

The carbon dioxide hanging over our heads

William H. Calvin [3]

There is a big heat-trapping blanket of greenhouse gases overhead. For carbon dioxide, it now amounts to a 50 percent excess atop the benign preindustrial concentration. Our most recent ambition, zero emissions annually, will not get rid of this legacy carbon dioxide, and it is what causes our climate problems.

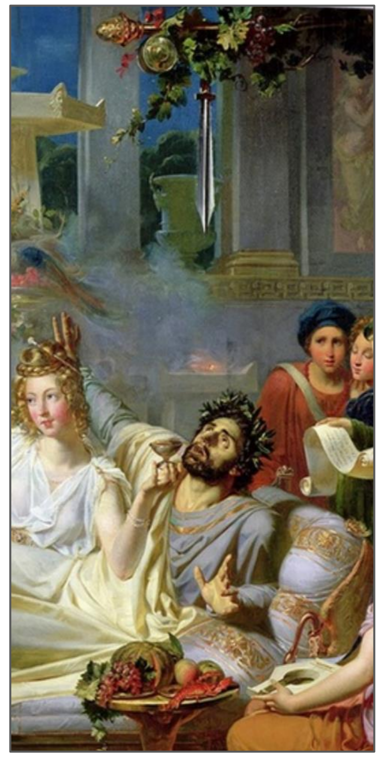

Figure 8. The Sword of Damocles, detail thanks to Felix Auvray.

In medical physiology, *emissions* is usually prefaced by *nocturnal*. (Perhaps that is how it came to apply to those fumes emerging from protruding tailpipes and tall smokestacks.) However, terming the excess CO_2 as 'emissions' tends to mislead us, as the invisible annual additions of CO_2 tend to stick around for far longer than mere fumes. Yet many people reason about CO_2 in the same way they reason about visible air pollution—and that minimizes the future danger.

"Wait!" you may say in surprise. "Emissions reduction has *worked* for similar problems such as urban air pollution and the ozone problem. It should work for carbon dioxide as well. Explain that!"

Such is indeed the reasoning behind our leaders telling us, year after year, to double down on emissions reduction. But those are flawed analogies. Nature cleans up visible air pollution such as haze, smoke, pollen, fumes, and smog with the next good rain. That means that reducing the emissions rate really does reduce the highest air concentration attained by accumulating irritants *before the next good rain arrives*. Yet that is not how things work for the molecular-sized greenhouse gases; nature's rate of removal can be 10,000 times slower than for haze and smoke.

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Furthermore, as a matter of a common cognitive ineptitude, people often confuse flow (a rate) with accumulation (a quantity). For example, it is all too easy to confuse a balanced budget (zero flow) with the national debt (what we must pay interest on, via taxes). Many people struggling with climate concepts will confuse emissions (a rate) with the excess CO_2 accumulation.

There are two more common confusions involving emissions. The same word ‘emissions’ is commonly used for both the flow rate and the accumulation, a conflation that forces you to guess what the speaker intended from the context. Try imagining a conversation where ‘miles’ could either mean a rate like speed, miles per hour—or it could mean a distance, the accumulation of miles traveled.

When mentioning ‘emissions’ without a qualifier, scientists usually have rates in mind. But even when we say ‘Annual emissions’ to make the rate connotation explicit, the phrase is often shortened by those who write graph labels and headlines.

Adding to this rate-accumulation confusion (economists call it the flow-stock confusion), input is often confused with net input, which is inflow minus the outflow of the same thing from a containment. After net zero is achieved by annually sinking as much extra CO_2 as we add that year, how long will nature need to take most of the excess carbon dioxide out of circulation? Rough answer: at the current rates, it takes 28 years for nature to clean up half of the 140-ppm excess.

Imagine we fixed our emissions tomorrow. There would still be a 50% excess of carbon dioxide overhead. ‘Net zero’ would only take us down to 350 ppm 28 years later. While 350 ppm has been proposed as a backing-up goal, on the way up that concentration was reached about 1990, after the continents started warming four times faster than the ocean surface in the mid-1980s. Thus 350 ppm is not a sufficient goal; it is still in the danger zone.

The 320 ppm of the mid-1960s, when the excess CO_2 was only 40 ppm, was the last ‘possibly safe’ concentration before the warming ramp began in the mid-1970s. Assuming we could shut down annual emissions tomorrow, how long would it then take for nature’s processes to cool the earth’s surface back to the surface temperatures associated with 320 ppm?

The fastest way is probably via increasing the sunlight reflected back out into space, the way that sea ice, clouds and hazy skies do. That is not a long-term silver bullet because it does nothing to address the other effect of rising CO_2: acidification of surface waters, which kills off the ocean's food chain.

Volcanic eruptions reaching the stratosphere cool us for several years; "under a white sky" is a good description of 1991 after the Mount Pinatubo eruption.

Natural carbon-cycle processes cool by cleaning up the lingering CO_2 excess: some sink CO_2 and organic debris into the ocean depths, others weather limestone, and some goes into fertilizing additional plant and plankton growth.

How long does all of that take—and how vulnerable is the CO_2 storage they utilize? The resulting CO_2 decay curve is not exponential with a 15-year time constant, as one might assume from plotting the early years on a semi-log graph and fitting a straight line. Essentially, stopping annual emissions today might see a 50% decrease in the excess carbon dioxide accumulation over the next 28 years. The natural removal processes for CO_2 will take a thousand years to draw the accumulation down to 20% remaining. Such a decay curve is said to have a "long, fat tail," tapering more like an alligator's than a dog's.

Now let us ask: How long, once sunk, will the excess carbon remain out of the carbon cycle's circulation loop, what traps that extra heat? Decades? Centuries? Millennia? Forever?

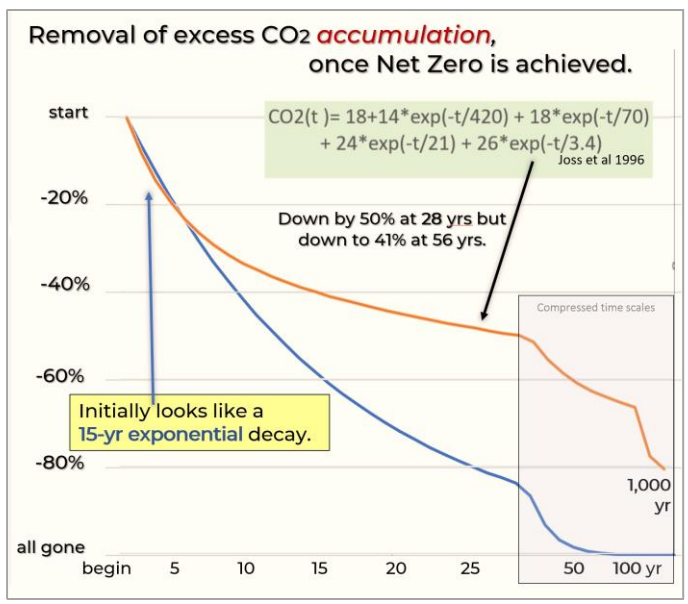

Figure 9. Nature's time course (orange) for getting rid of extra carbon dioxide once the annual additions stop; from Joos et al (1996). Blue line shows what an exponential fit to the first decade would have suggested about the future time course. After 28 years, natural processes have only removed about half of the excess. Another 28 years only reduces the excess by an additional 8%.

It depends. New grass takes CO_2 out of the air, but it decomposes or burns in several years, putting most of that CO_2 back into the air. If leaves fall off and rot every winter, they don't count, only the carbon in whatever wood growth remains alive.

A new tree reaches maturity in 30-50 years; that is when rot within the tree increases enough to release, via bacterial respiration, as much CO_2 as new growth captures elsewhere as wood. At maturity, a tree ceases being a *net* carbon sink. Indeed, it continues to be an expense, needing protection from drought, fire, and bark beetle—all of which put the stored carbon back into the air as CO_2 over the next year. There are many good reasons to plant more trees, but 21st-century climate relief may not be among them.

And, in the coming decades until we can remove enough CO_2 annually to stave off slippery slopes, we need to keep the trees we already have. Because a tree's replacement may take a half-century to achieve the same carbon storage, it may prove necessary to stop cutting down whole forests. Putting stored CO_2 back into circulation now must be avoided for all storage sources, not merely the fossil fuels underground. Furniture or wooden buildings may have eighty-year lifetimes, but paper products often revert to CO_2 or methane CH_3 within a few years.

The ocean depths (the 98% below the wind-mixed surface layer) are a much better long-term sink than are forests. There is no fire or drought down there, not even beetles. Deep ocean already has so much suspended carbon debris that sinking all of our excess CO_2 below the thermocline would only increase the total by several percent. It is often a thousand years (about thirty human generations) before deep waters begin to circulate back up to the surface, allowing excess CO_2 to slowly creep back into the air overhead during the following few millennia.

The amount of annual carbon debris that reaches the bottom to become sediment is less than one percent of what stays suspended in the ocean depths, so the deep *suspended* debris and attendant CO_2 is the big carbon sink on the millennial time scale, a suitable candidate for storing the excess carbon now in circulation. Below the thermocline is where much of the excess carbon will eventually go in any event; what we need to do is to speed up the natural processes.

"Carbon sink" is usually meant as a metaphor—but here *sinking* is to be taken literally.

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Climate's Big Picture

Overnight heatwaves will need A/C powered by small modular reactors

William H. Calvin[4]

Is emissions reduction actually working? Only in some segments of some countries—and it is global that counts because of mixing. Rather than the global CO_2 curve starting to flatten, the rise just keeps accelerating.

Whatever developed countries do to reverse this trend, there will be increased emissions from modernization in developing countries. Despite rate reductions achieved in some developed countries, the CO_2 growth curve is now 50% steeper than in the 1990s.

Already, most of the deaths from extreme weather come from heatwaves. Putting on my Ph.D. physiologist's hat for a moment, let me say that peak daytime temperature is not a good way to characterize a lethal heatwave. I'd pick something like the nighttime low staying up in the range where sleep is impossible because of the need to fan and drink water for sweating—and doing so for a third straight night.

Think ahead to when developing countries get hit by deadly heat waves. Air conditioning will become essential for surviving a string of hot nights. Children and elders keep dying in the hot nights from heat stroke (after several sleepless nights, caregivers become unreliable about insisting they drink more; caregivers may also fall down the stairs). Brownouts will be intolerable. A government that fails to provide more

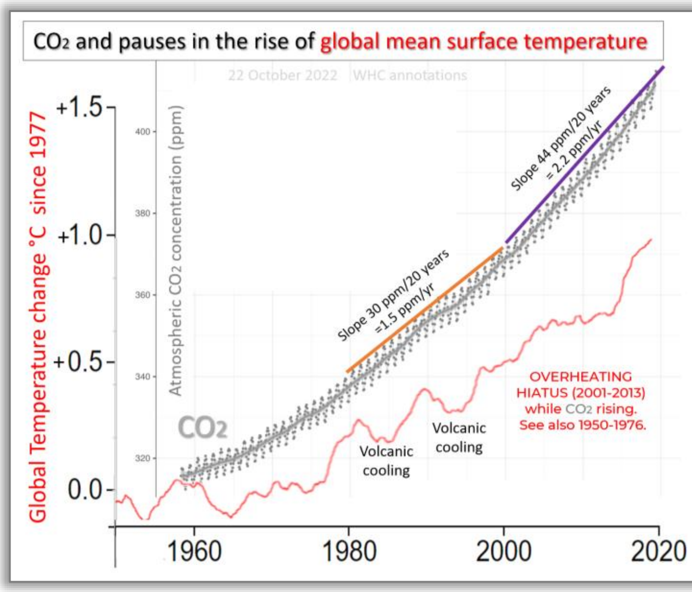

Figure 10. The rising carbon dioxide concentration since 1958. It did not slow during the 2001-2013 warming hiatus; rather, it accelerated almost 50 percent. The annual rise in CO_2 is equal to the emissions rate minus the portion that is annually removed to long-term storage via ocean processes and added growth on land. Data: Scripps and NOAA; lines fit by hand, annotated by WHC. Four-year smoothing of global temperature.

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power will be overthrown and the local fossil fuels will be used to better prepare for future summers.

Will developed countries try to compensate the others for the unearned climate troubles they face? I hope so—but just to protect

Facing a power crisis and searing heat, India falls back on coal

Although India has pledged to be a leader in renewable energy, recent weeks have shown the country is still heavily reliant on coal to meet soaring power demand.

Figure 11. An indicator of the coal surge to come?

their own interests, developed countries now need to provide the others with reliable, inexpensive electrical power alternatives—and well in advance. There is a lot of coal in the world; we must now prevent mining it.

There are also a lot of trees in the world; we can no longer cut down whole forests because new growth takes 30-50 years to remove the CO_2 burden they create when earlier burned or decomposed. “Yes, but they grow back—so they are renewables” is no longer a valid excuse when there is immediate risk in the meantime.

Wind and solar are intermittent, and only some of the countries can generate enough hydroelectric power in a drought, So, to reliably sleep through the hot nights, nuclear power will likely be needed to avoid burning local coal. Nuclear fission has proved to be the most reliable of the various electricity sources. Even including the uranium mining, nuclear power’s footprint is far less than that of hydro’s reservoir acreage and that for solar (not to mention surface coal mining).

Providing for the heatwave countries need not involve building them a big 1,000-megawatt nuclear power plant of the old style familiar to us. Small modular reactors (SMRs) are about a thousand times smaller than conventional power reactors, limiting the damage if something went wrong with one. Sixty years of design improvements have gone into the SMRs, which are built in factories for installation elsewhere. Some SMRs are designed to operate for up to thirty years without refueling.

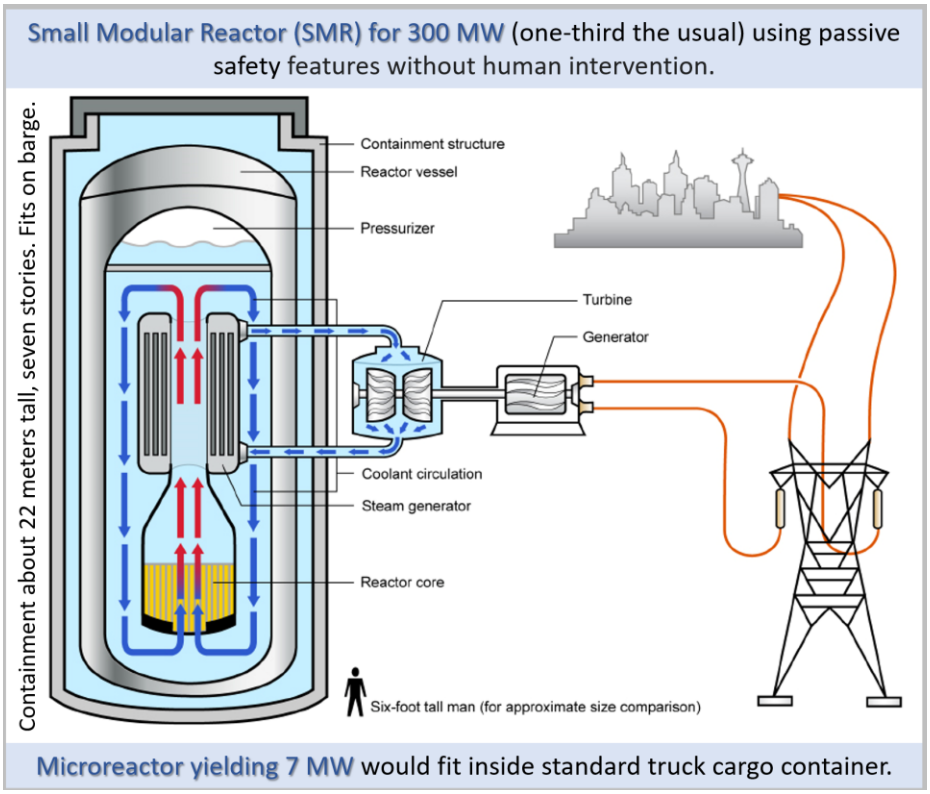

Figure 12. Small Modular Reactors (SMRs) and microreactors.

SMRs can be constructed on [ocean-going barges] so that they can be towed up rivers at the destination and swapped for a module needing maintenance back at the factory. The ocean would provide a heat sink during transport; scuttling would defeat pirates.

Figure 13. The first SMR on a Russian barge being towed to a Siberian coastal site.

The coastal or riverside steam-powered generators could be owned and maintained locally; they would be, after all, as low tech as coal plants, given that the barge could instantly switch to the surrounding water for a heat sink should the steam plant fail.

The leased reactor heat source for the steam would come and go, maintained and refueled in a capable country with better security. (Currently, the US, France, Russia, UK, Japan, Finland, and probably China can recycle nuclear waste.) Were fissile matter to be discovered missing, the destination country would likely lose its access for refueling any of its SMRs. Were terrorists to dynamite an SMR, the fallout area would likely be on a scale similar to the flash flooding from blowing up a dam, not that of a Chernobyl disaster that spreads to neighboring countries. In an age of cruise missiles and drones, many small reactors seem the better bet.

During the weeks after pushing the big red button to lower the control rods that stop a self-sustaining chain reaction, one still needs to counter the lingering heat generation from unstable fission by-products. They continue splitting into ever-lighter elements until reaching Lead-206 (this ordinary radioactive decay lacks the self-sustaining chain reactions that renew the supply of free neutrons). It has been the aftermath cooling failures that have caused meltdowns and allowed steam pressure to increase enough to scatter fallout. The fires that follow can double the fallout.

The 1986 Chernobyl disaster was similar but made much worse by the lack of a thick containment dome, by the manual shutdown of protective systems for a test, by a dangerous control rod design that should never have made it off the drawing board, and then by a stubborn boss in the reactor's control room on the night shift. He ignored the warnings of his two better-trained assistants; he threatened to fire them if they did not implement the restart. The restart promptly led to the steam explosion and fallout. The boss survived; his assistants did not.

The 1960s reactor designs were the basis for many nuclear power plants still operating today. The designs were adapted from the US navy's 1950s reactor designs for powering ships surrounded by a vast expanse of cool seawater. The land-based commercial designs did not adequately analyze the failure modes involving cooling after the chain reaction was shut down. Early failures such as Three Mile Island in 1979 reflected poor plumbing design.

At the coastal Fukushima reactors in 2011, the tsunami's wave height of fifteen meters (five stories) was that predicted eighteen years earlier by scientists analyzing the offshore seafloor slope. Both plant owners and government regulators ignored their warnings. (Something similar keeps happening with climate.)

The 2011 tsunami following the offshore 9.0 earthquake destroyed the diesel backup generators for Fukushima's cooldown water pumps. After bringing in replacement generators on trailers, it was found that the control boxes for auxiliary power had been shorted out by salt-water flooding. The switchboxes had been left in the basement and never relocated to the upper floors of the building after the scientists' tsunami analysis. While possible, workarounds take time, more than emergencies usually permit.

Such design and regulatory failures are the reasons that some reactors have destroyed themselves (not via explosions but by gradual overheating) and exposed some toxic byproducts in a meltdown. The parent chain reactions have been shut down successfully but cooling in the aftermath was the failure mode. The 21st-century cooling system for barge SMRs can always be supplemented by scuttling the barge when all else fails.

Current power reactor designs appear to be much safer, just as vehicles have become much safer since the 1950s. With SMRs and micro-reactors, we need not think that giving SMR-scale nuclear power to a heatwave-prone developing country is giving them an opportunity to build a bomb. Something like the floating SMR is among the things we must do before we get hit by more extreme weather surges that demand much more electrical power from local fossil fuels.

Call it the *21st-century Lend-Lease Program*.

—to be continued—1294 words

Climate's Big Picture

Will climate change be gradual? (That's *so 20th-century!*)

WILLIAM H. CALVIN [5]

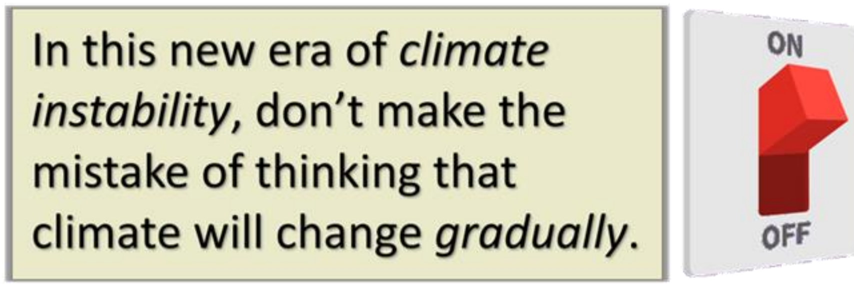

Figure 14. Climate instability

A year-after-year creep of climate problems was easy to assume in the 20th century. The forcing factor, extra carbon dioxide overhead, was only gradually building up. Once global overheating started up in 1976, it seemed gradual, except for some pauses due to other influencers such as volcanic eruptions. The expansion of the tropics and the rise of sea level were both gradual, as has been the loss of species. And we scientists kept talking of the consequences of gradual—say, by the end of the 21st century—because we were still struggling to understand the dynamics.

The obvious analogy for 20th-century climate change seemed to be a dimmer switch: push up a little more and things become brighter. But 21st-century climate turns out to have some features of the original snap-action light switch that tends to abruptly blind one in the middle of the night.

Any suggestions of sudden change atop the gradual drift were deprecated in the big climate reports as mere speculation. This was not the best standard for warning nonscientists of trouble ahead. Climate scientists were all too aware of the Cassandra problem, a term now used for a person whose accurate forecast is not believed. They stuck to gradual in their explanations and warnings. But the sudden surges in 21st-century extreme weather have rather forced the issue.

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It is time to consider the fast dynamics and flips that can make climate change abrupt, a topic I first broached in "The great climate flip-flop," my cover story for the January 1998 issue of *The Atlantic*. Nature offers many examples of hair-triggers. One setup for abrupt transitions is when two large opposing forces have different response times to a nudge, so that amplifying feedback briefly creates a slippery slope in the interim.

To understand how gradual change can turn sudden, consider a tug-of-war where large opposing forces are usually kept in balance. But once they are unbalanced by a team member's shoe slipping along the ground, there can be a quick surge if reaction times are unequal in the opposing teams.

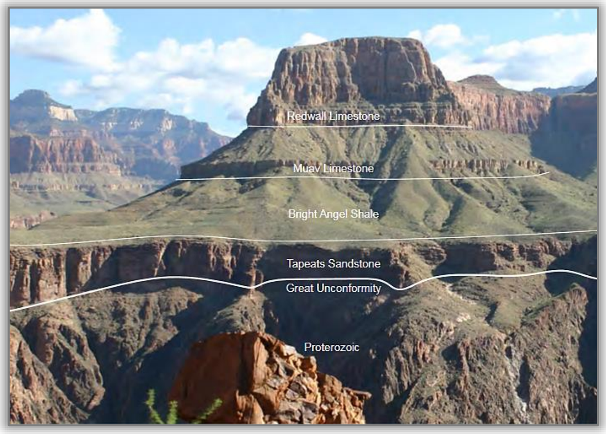

Figure 15. The Great Unconformity exposed in the Grand Canyon separates the Tapeats Sandstone from ancient Proterozoic rocks. The Great Unconformity represents 1.2 billion years of missing rock record.
Credit: Arizona Geological Survey.

In the earth sciences, there is a firm tradition, going back several centuries, of expecting gradual processes to be behind anything that initially appears to be sudden. Charles Darwin learned it from the reasoned explanations of his future friend Charles Lyall while reading his geology book, *Principles of Geology* (1830), during the voyage of the Beagle.

Distinct geological layers where, say, desert sandstone is abruptly topped by shale from a mud flat, make one initially suspect a sudden climate change. In Europe it was called catastrophism. But layer-dating methods eventually showed that such marked transitions involve missing layers, where erosion had sanded things down before another layer was slowly added to the new surface. Such "unconformities" make a cliff face look like a layer cake and would do so even if climate change had been gradual all along.

Even today, proposing sudden changes, especially catastrophes, may be treated as a first guess, something not yet sufficiently well-considered, and perhaps safe to ignore for a while. Caution certainly slowed, by several decades, the acceptance of ice core evidence from Greenland showing there really had been abrupt climate transitions.

In 1983, my third year of regularly attending any ice-age lectures in search of what had been speeding up prehuman brain enlargement, the Swiss geochemist Hans Oeschger visited the climate science community in Seattle. In passing, he showed slides of abrupt temperature jumps in the DYE3 core on the southwest shoulder of the Greenland ice sheet.

I immediately asked him several questions about the exact transition duration, since I had been studying such things when brain cells "spiked." And Oeschger confirmed, quite emphatically, that there were indeed warming transitions in the North Atlantic climate of "Just a *few* years."

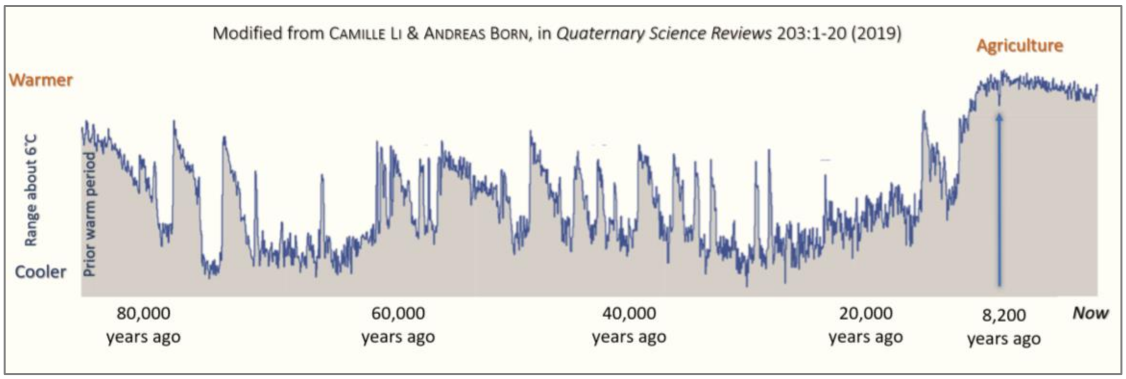

Figure 16. Abrupt re-warmings and coolings during the most recent ice age. "Now" on the right is preindustrial. From the NGRIP core at 75°N on Greenland's top ridgeline.

The new warmer climate would last a few hundred years before cooling back down over a few decades. The most recent such flip went down at 12,900 years ago and then suddenly up at 11,700 years ago; it was the longest downtime observed. That cooling event was already known to the scientists studying fossil pollen in Scandinavian lake beds; they had named it the Younger Dryas. Lake bottom cores do not have the time resolution to see the century-scale transitions (worms stir the sediments above the anoxic layers) but by 1993 there were miles-deep ice cores with annual layers to count.

It was, as the glaciologist Richard Alley later said, "a three-mile time machine" into the last 130,000 years. Climate scientist Peter Demenocal wrote in 2005 that "When I was a graduate student, we learned that the warming that defined the end of an ice age occurred very gradually, over the course of many thousands of years. This view of sluggish climate changes was shattered… when scientists discovered that the main warming events that ended the last ice age took place within less than a decade."

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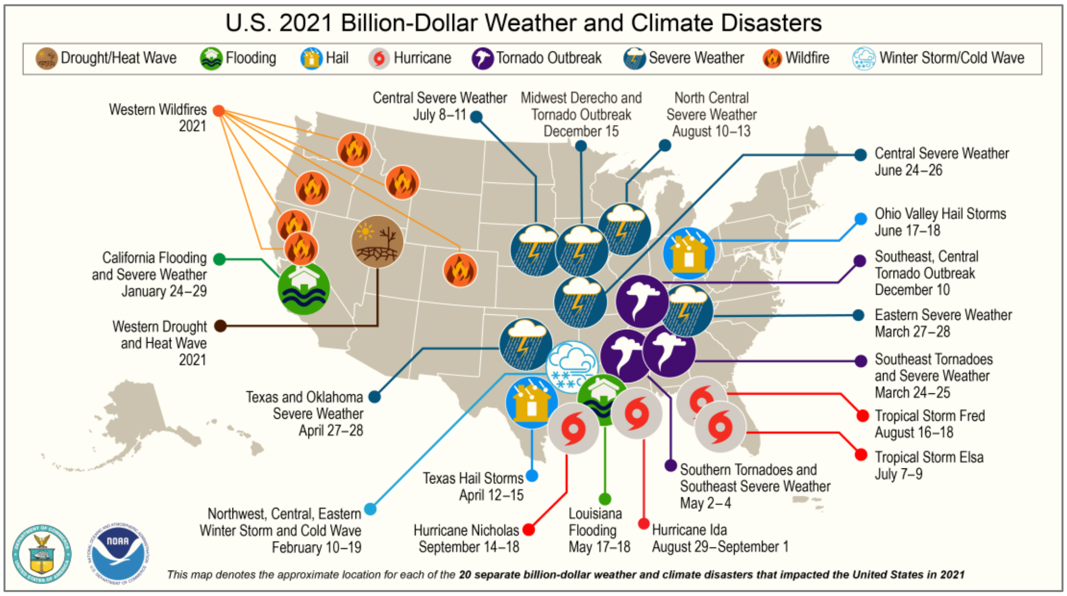

Figure 17. 2021 US $1b+ extreme weather

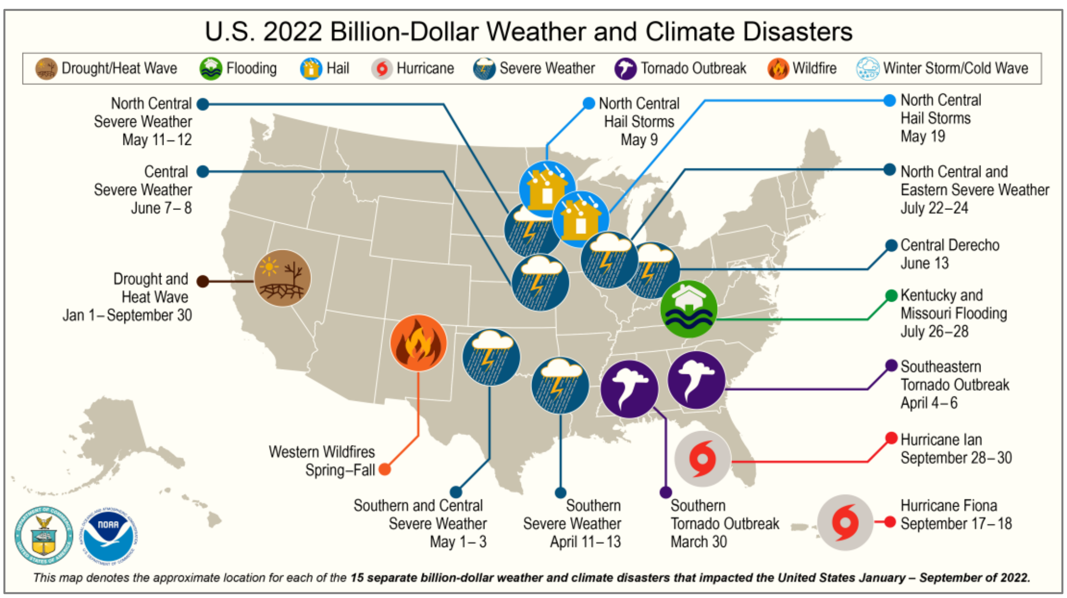

Figure 18. 2022 US $1b+ extreme weather

Climate's Big Picture

21st-century surges in extreme weather

WILLIAM H. CALVIN [6]

Figure 19. Did this move lawmakers?

The rise in excess CO_2 has been gradual. Many expected the climate response to track this provocation gradually. And some 20th-century aspects of the response were indeed gradual, as in the expansion of the tropics and the rise in sea level. But sometimes the climate response can be as sudden as the trade wind disorganization that initiates an El Niño, our big worldwide climate shift (but one that usually shifts back after several years—except when it takes a century).

In an El Niño, climate flips into a new state within a year, thereby rearranging where the humidified ocean breezes deliver their moisture on continents. Southern California gets atmospheric rivers of rain from Hawaii during El Niño years. The "Banana Express" comes ashore up in Portland and Seattle in La Niña years when low-latitude trade winds are exceptionally strong and steady. Sometimes this goes on for three years, showing how steplike climate change might get started. But note that some El Nino's in the Middle Ages lasted decades—even a century—with their droughts triggering political revolutions in synchrony around the world.

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Rather than using the customary global temperature averages, let me focus on the really big episodes of extreme weather, asking whether they are becoming much worse or much more frequent. Back-to-back episodes of such severe weather could collapse our civilization long before the summer heat waves get around to it, just as drought ended many earlier societies since dug up by archeologists. We now have examples of what might have saved a civilization, had it been done promptly.

Climate scientists have attempted to address the increase in extreme events by skimming off the top 10% of a cumulative probability distribution—say, for the power in hurricanes. As in the "Black Swan" events, there usually is not enough data out in the tails to use.

Climate scientists had warned, even back in the 1960s before computerized models of climate change were possible, that more extreme weather was going to happen. However, I cannot recall anyone venturing to suggest that extreme weather would worsen in sudden steps.

That included me, even with my several decades of studying how nerve impulses were suddenly triggered when sodium ion currents exceeded the less nimble potassium ion currents. I had decades of paying close attention to abrupt climate changes of the past, in search of its triggers. I still missed the possibility of extreme weather surges—until after they happened in the first decade of the 21st century. It took another half-dozen years to look back to see if the five steps were sustained or just random clustering. It was surge-and-stay.

What I found useful was NOAA's extreme weather database that, beginning in 1980, skims off the biggest events by counting the annual number of episodes causing more than US $1b damage. The insurance claims are corrected to account for the estimated uninsured losses. It has been suggested that this underestimates total damage by 10-15%. But in counting the number of big events, it hardly matters whether the threshold for inclusion is $900m or $1b, as long as it is corrected for inflation to stay the same over the decades. I ignore NOAA's focus on total losses per episode averaged over a year; that depends on where storms come ashore. What I want is a reasonable estimate of the annual number of "big ones" so I can see if surges occur.

Not all types of extreme weather have worsened: after 2000 there were about 35% fewer $1b-or-more cold events (both icy winter storms that linger and big freezes in growing season).

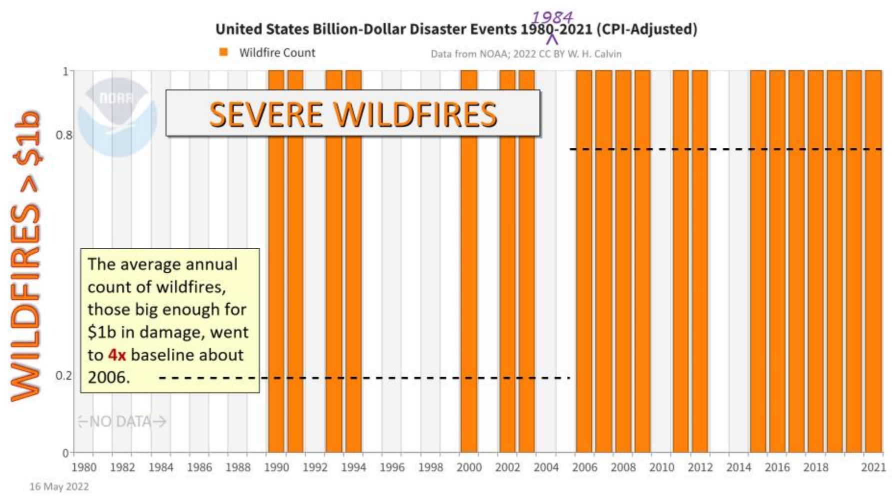

Figure 20. The 2006 surge in US big wildfire years.

One sees that the annual number of US **severe wildfires** were up **4x** after 2006; since the number of reported fires did no such thing, the severity increase is unlikely to be more arsonists, careless campers, or lightning strikes. The step up is likely to be in fire duration and spread, via what is called fire weather (the triple combination of hot-dry-windy).

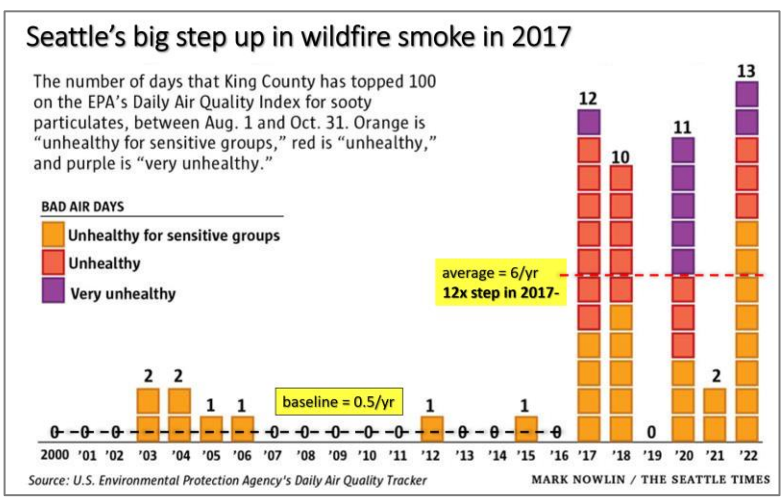

Figure 21. *The Seattle Smoke*, while it contains contributions from fires in the North Cascades, is usually dominated by smelly orange smoke blown north from big fires in Oregon and California.

Timothy Egan gives an example from 1910 in his book, *The Big Burn*. In just a day and a half, the largest wildfire in U.S. history devoured 3 million acres in eastern Washington, Idaho and Montana. That is about the size of

Connecticut. Hurricane-force winds, more than 80 mph (130 km/h), came out of eastern Washington to spread numerous small fires faster than a horse could run.

Here in Seattle, we have had our own big step up in heavy smoke days (AQI>100), now a common problem on the US west coast in late summer. Starting in 2017, we jumped to averaging 12x the baseline number of heavy smoke days. As I was writing this, indoor eye irritation was so great for a week that my computer had to read this manuscript aloud to me so I could keep my eyes closed most of the time. For a while, I stuck to narrated books.

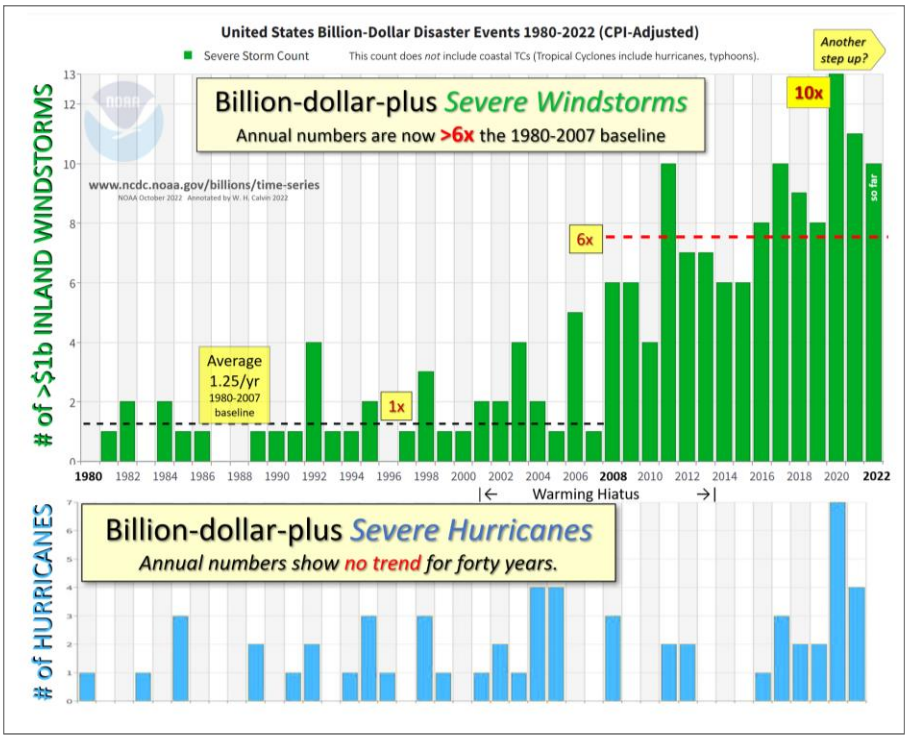

Figure 22. The annual number of severe (>US$1b damage) windstorms in the inland U.S. averaged **6x** the prior baseline after 2007, with a 10x peak in 2020. The NOAA inland windstorm category includes high winds, severe tornado swarms, derechos, and hailstorms; one episode might include a hundred tornados. Equally severe **hurricanes (lower)** are in a NOAA category of their own; their rate for billion-dollar episodes stayed flat from 1980 through 2019 even though other measures have shown intensification over time.

Severe windstorms were up **6x** after 2008, with **10x** in 2020. It is time to quickly underground power lines, both major and minor. In recent years, derechos have caused power outages lasting weeks—some in the midst of heatwaves, so that people were without air conditioning and refrigeration for food.

Severe floods were up **3.4x** after 2010. It is time to move the vulnerable to higher ground and let them commute to jobs in areas that can be flooded such as most of New Orleans.

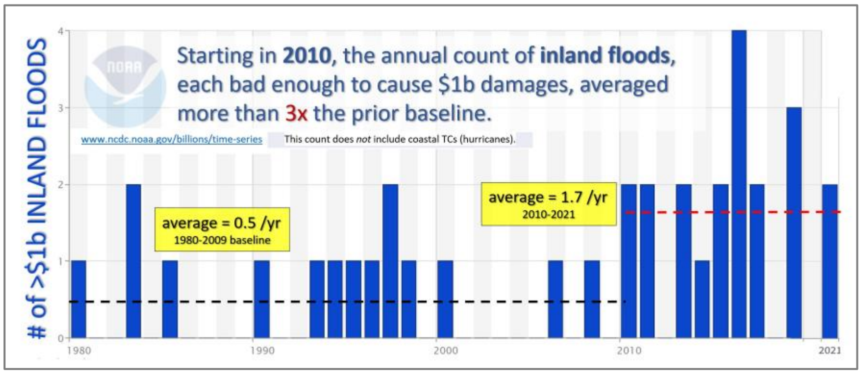

Figure 23. The 2010 3x surge in the annual number of US big inland floods.

None of those surges have retreated. My inflation-corrected NOAA categories are all inland episodes; they do not include the winds and coastal floods from hurricanes, counted separately.

Those three surges—winds, floods, and wildfires—involve annual numbers stepping up three times or more. But there are also two types of extreme weather that are too infrequent for us to speak of annual rates. I have included them because they show an order-of-magnitude step up in impact, compared to prior large episodes.

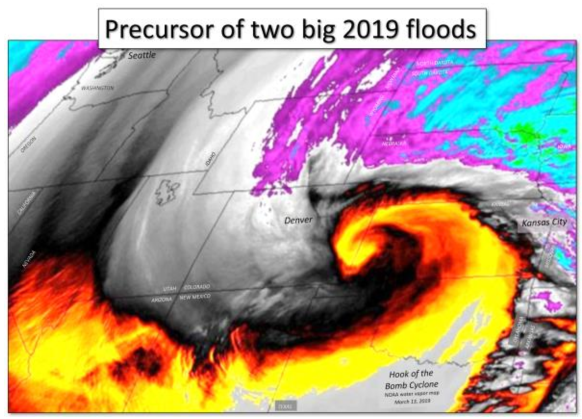

Figure 24. This rapidly developing "bomb cyclone" caused a billion-dollar flood on the Missouri River and another on the upper Mississippi River above their confluence in St. Louis.

I only include them when there are subsequent repeats of an initial episode. Thus, they are not the rare “black swan” extreme events that they are initially assumed to be. Instead, they are new players on the present-generation time scale, forcing us to act urgently to protect our children and ourselves.

Hurricanes in general did not surge (by my 3x criterion) in either severity or annual numbers, but some began to stall, spending days rather than hours within 100 km of a locale.

The first named **hurricane that stalled** was 2002 Hurricane Isidore in the Yucatan (lingering 78 hours); the second was 2017 Hurricane Harvey

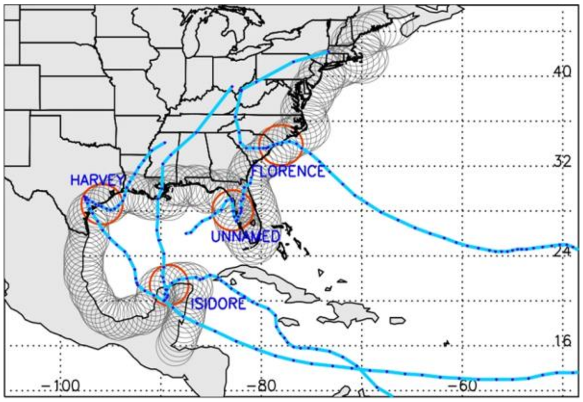

Figure 25. Four stalled hurricanes analyzed by Hall & Kossin (2019). Circles for each coastal locale are 200-km diameter; data dots are six hours apart. The number of dots within a red circle, times six, is the measure of stalling in hours.

near Houston, that lingered for 108 hours rather than passing over in the usual 5-8 hours—an order of magnitude increase. A third, 2018 Florence, stalled for 76 hours while heading west over North Carolina. There is at least one predecessor, from back in the era before hurricanes were given names, the 1968 hurricane that hung around Tampa Bay, Florida, for 90 hours.

The usual heatwaves that trigger big headlines are like the 1995 Chicago heatwave, which killed 739 within a week. The 1988 heatwave in the US Midwest and Canada was a very long hot summer, killing thousands. The 2022 European heat wave is said to have killed thousands, spread over several months. But those were not megas. The month-long megas were two orders of magnitude more deadly than the usual severe heatwaves that make for big headlines.

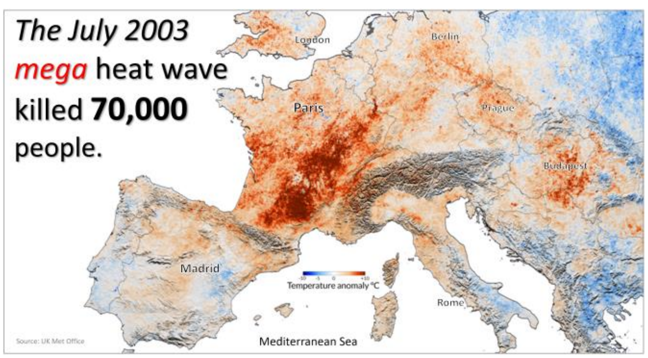

Figure 26. The first mega heatwave. "Anomaly" means the temperature difference above or below the long-term average for that place in July.

The first **mega heatwave** was in July 2003, killing 70,000 Europeans in about a month. Several time zones farther east, the second mega killed 56,000 Russians in July 2010.

More frequent also implies a greater chance of compounding and cascading, producing 'compound extremes', those back-to-back episodes that can set up a "perfect storm." For example, both megas were preceded by springtime droughts that set the stage for a loss of evaporative cooling of the land surface in mid-summer. But even if there were no causal linkage between two extreme episodes, back-to-back could strain relief efforts to the point of institutional collapse and civil war.

Severe extreme weather is the threat to watch, not merely the next fractional degree of overheating, which has proved an unreliable predictor of 21st-century climate trouble.

to be continued—1487 words

Climate's Big Picture

Climate surprises and slippery slopes

WILLIAM H. CALVIN[7]

Climate change is not as simple as **excess CO_2** leads to **overheating**, which in turn leads to excesses of **extreme weather**. Those relationships are probably still true when averaging over a century, but we no longer have so much time, having just lost a half-century to half-measures.

We can no longer assume that overheating will track excess CO_2—or that preventing further overheating will protect us from extreme weather surges. There are already too many counterexamples, omitted from the standard story.

The Big Five surge-and-stays all began during the pause in global overheating ("The Hiatus" between 2001 and 2013), contrary to expectations that extreme weather would track overheating—and, furthermore, that overheating would track emissions rate (which accelerated during the hiatus rather than retreating). Thus, at least on the time scale of a decade, two major inferences were violated.

The CO_2 concentration rose 50 percent faster than it had in the late 20th century—yet the pause in overheating continued. In the hiatus, both links in the usual emissions-to-overheating-to-extreme weather causal chain were violated for fourteen years. Nonlinear systems are full of surprises.

Where did the additional trapped energy from the sun go during those years of accumulating CO_2, if not showing up in the kinetic energy of molecules, which we measure as air and ocean surface temperatures? This has not been sorted out yet but I can offer an example. One non-temperature destination for the new energy might be providing the kinetic energy needed to double the length of the polar jet stream with meanders without cutting its speed 31%. More switchbacks promote additional extreme weather in the mid-latitudes.

So many climate developments have been contrary to reasonable cause-and-effect expectations. There is a lot to explain, and we are not exactly

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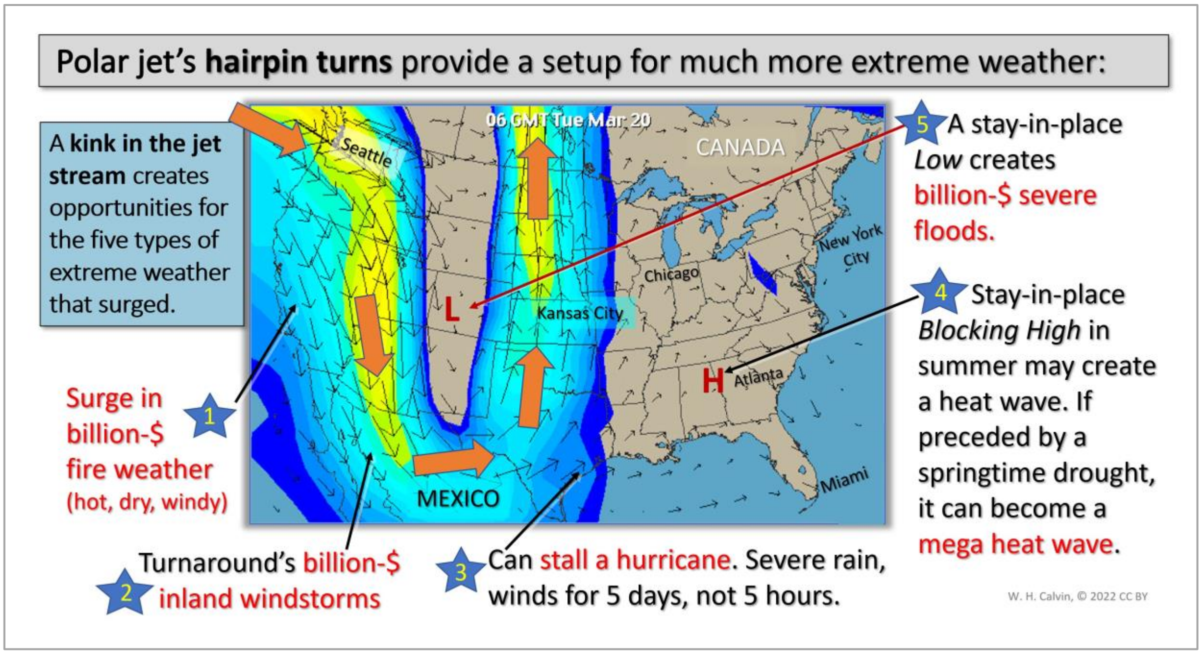

Figure 27. A kink in the meandering polar jet stream, reaching from Canada to Mexico and back again 1,100 km (700 miles) farther east. Hairpin turns provide an additional source of the Big Five types of extreme weather. Not all extreme weather opportunities actually occurred on this day in 2014 but same-day around the globe multiple events do happen, as on July 22, 2018 (see Mann 2019).

pouring research money into the field to understand this nonlinear system more quickly. Nor are we training new engineers fast enough for the challenges ahead.

Climate Action naturally divides into *Climate Defense* and *Climate Repair*. Yet the only actions we hear about are two subdivisions of defense: *mitigation* (softening the blow by slowing it, as by slowing additional emissions), and *adaptation* (more reservoirs and food stockpiles, building underground dwellings to mimic cool caves). Pairing mitigation with adaptation, but omitting any mention of climate repairs, leads to the inference that the blow is inevitable, that there is no way to back out of the danger zone. By our reluctance to discuss climate repair, we are sending the wrong message. In order to refocus our efforts, we need to reframe what the climate problem is.

If fatalists take over, it will create danger for the rest of us. Fatalists tend to treat the earth as a slum in the making, as when leaky roofs and potholes are not repaired because of the perceived downhill trend and the declining tax base to fund repairs.

We can no longer rely on imagining several knock-on stages of causation: annual emissions, which lacking a cleanup cause CO_2 accumulation overhead, in turn causing overheating, a consequence of which is more extreme weather. Simple cause-and-effect reasoning is failing us because we are dealing with a complex system having nonlinear dynamics.

There exists a web of interactions and quasi-stabilities that create thresholds for flipping into a new state of the system, rather like shifting gears or a horse switching gaits. I studied three different complex dynamical systems during my career: Darwinian brain circuitry for improving novel movement plans; how new species can stabilize in Darwinian evolution rather than backsliding when climate change reverts; and how the climate can suddenly lurch. I know that many will have trouble understanding the probability distributions that are replacing either-this-or-that certainties.

With extreme weather, at least, we are not solely dependent on predictions, the way we were in the 1970s before the overheating ramp finally began. Many have already experienced the new extreme weather—and probably want to do something about it.

—to be continued—813 words

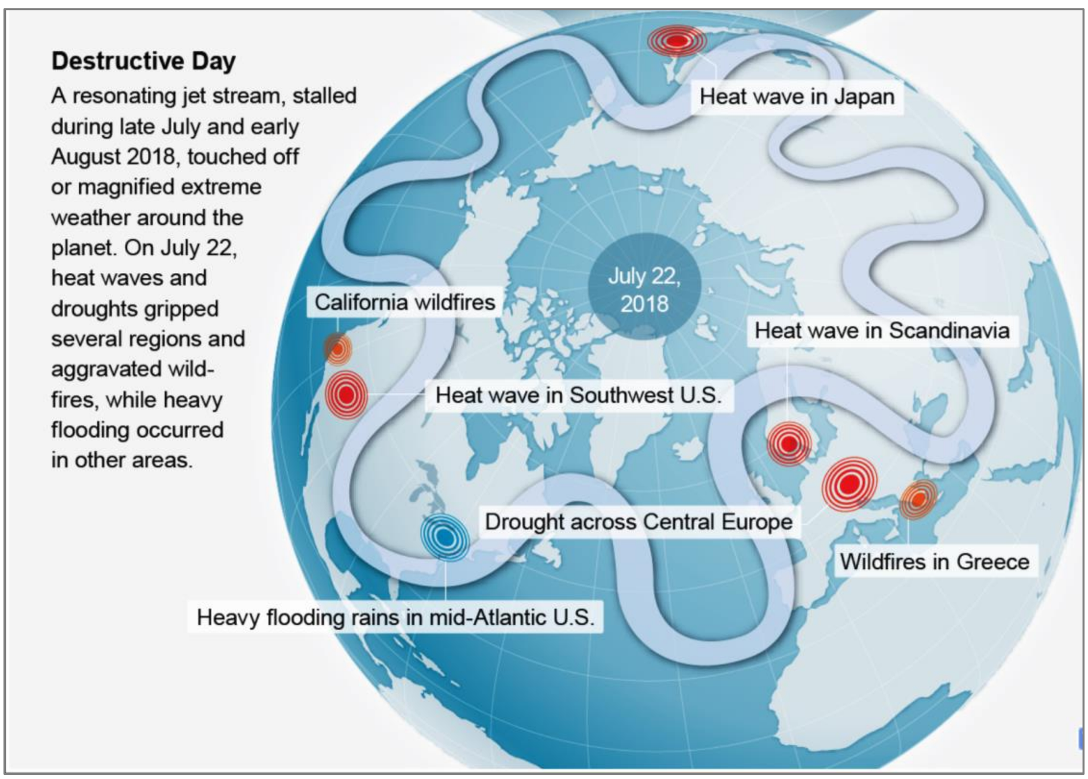

Figure 29. A day when extreme weather occurred around the world as the jet stream path resonated, producing seven deeply penetrating loops. Thanks to Michael Mann and *Scientific American* (2019).

Climate's Big Picture

Heading off climate-triggered collapse

WILLIAM H. CALVIN[8]

Climate action can no longer wait for better scientific understanding: we have run out of time for that. Physicians often face such situations: a patient who will soon collapse and die unless something imperfect is attempted.

In addition to climate shifts themselves, there are also substantial cultural hazards that could hasten collapse. Anarchists may attract people who merely think that "things need shaking up" but persistent anarchists may be both short-sighted and suicidal; they also treat life as cheap. Given a popular guru, even humane religions can be hijacked as a front for this, as we saw in the mid-1990s with the Aum Shinrikyo doomsday cult in Japan and Russia.

Aum hoped that their sarin poisoning of judges and subway stations would create an international blame game resulting in a nuclear war, one that would allow Aum members (somehow exempt) to inherit the earth. Their recruitment efforts targeted those with engineering and medical educations.

What to do? At least on the climate engineering side, that is an easier question. Presently, there are three general types of climate action plans; for simplicity, I will call them *Diet*, *Shade*, and *Cleanup* to avoid the names of specific methods. After fifty years of failing at an emissions reduction *Diet*, we now need a big additional focus on cleaning up what accumulated in the meantime while we denied and postponed.

I say 'additional' because nearly all emissions reduction efforts were important for other economic or environmental reasons before they claimed every-little-bit-counts relevance for climate as well. They will remain important for their original non-climate reasons. Because even though their long-term efficacy is poor, we will need to continue the reduction efforts as we ramp up the sinking of excess carbon.

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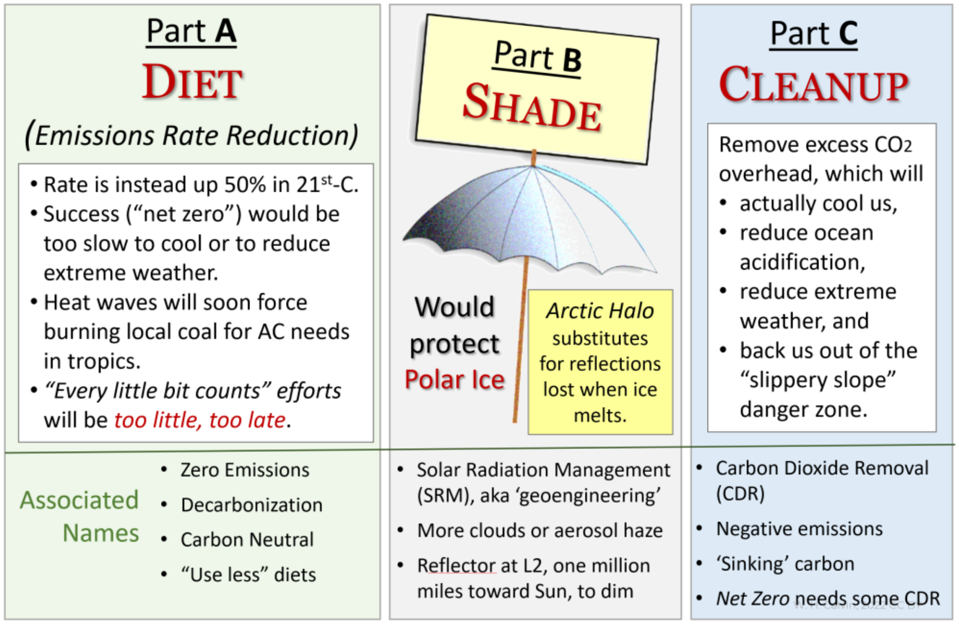


Figure 30. The three major types of climate action, and their common names.

But note that the climate threat has accelerated and that reliance on minor actors can now mislead us (in the manner of whitewashing) into thinking that the appropriate climate actions are already in motion. The era for the usual long-term thinking about climate action has passed; so has the era of not-good-enough-yet hesitation about counter-measures. The fixes now need to be big and quick because of extreme weather threatening our food supply and infrastructure. To protect carbon dioxide *Cleanup* projects (and us) in the meantime, we will also need some *Shade* projects.

And yes, they may have some undesirable side effects—but we can no longer wait. Again, the medical mindset is relevant: as with cancer chemotherapy, we are seeing the price of past inattention, denial, and repeated political efforts to slow down research, even the Mauna Loa measurement of CO_2 concentration. Now we are forced to risk some treatment side effects in order to keep going.

Physicians are all too familiar with the threat of cascading collapse (again, seldom emphasized in climate appraisals). Pancaking of the lower floors by the upper floors collapsing has become familiar from watching videos of the World Trade Center in 2001 and, in 2021, the Champlain Towers South high-rise in Surfside, just north of Miami Beach, Florida.

Because of so much extreme weather, we must now do the *Cleanup* quickly, with big carbon dioxide removal projects. But so far, motivating such cleanup has proved an example of what economists call the "tragedy of the commons" where shared free use of a common resource—say, roommates sharing their one kitchen—leaves no one likely to clean up someone else's mess.

However, to avoid the mega version of the tragedy of the commons, multiple countries should get started on the cleanup—the situation is so urgent that there is now no time to first spend a decade negotiating cost-sharing treaties and worrying about governance or climate justice. Start on such aspects, by all means, but they can no longer be allowed to delay the first stages of effective climate action. Instead, suggest there is a race on, with perpetual bragging rights for the countries that create or fund the breakthroughs that save the world.

There is a big lead time for doing something effective about climate change—actually backing us out of the extreme weather danger zone. Our current ambition is to merely slow down the collapse of civilization. Why so little ambition?

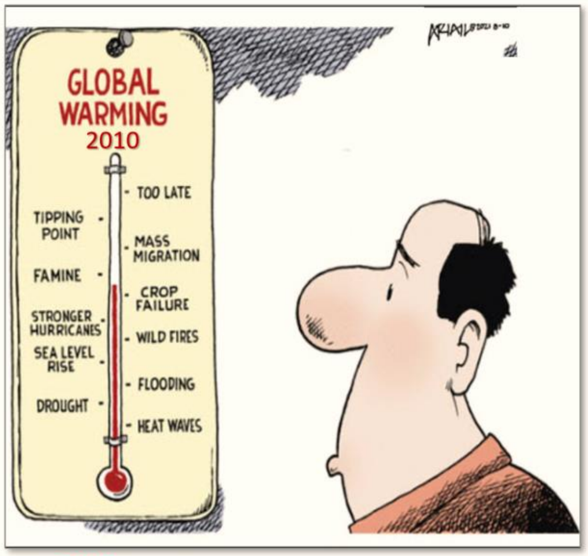
Gradual overheating, secondary to the excess CO_2 buildup from emissions, is no longer the correct focus for understanding the risk we now face from climate disruption. Because of surges in extreme weather, we are already in climate emergency territory, where fast tracks to disaster must be forestalled.

One must survive the short-run in order to make the long-run relevant—that's the focus in Emergency Medicine. Their mindset is what addressing the climate crisis now requires. The surges in extreme weather—especially during the 2001-2013 pause in global overheating—have shown that we already have a bigger climate problem than gradual emissions reduction can handle.

Emissions reduction has now become what, in medicine, would be called an *adjuvant*, a supplementary treatment that is ineffective by itself but augments a more effective treatment. Chemotherapy would be ineffective for a large tumor but, following surgical removal, chemo helps clean up the small metastases and left-behind fragments.

Carbon *Dieting* was once the primary treatment for climate disease. Now its status has been reduced to that of an adjuvant. Shade engineering is also an adjuvant, being ineffective for backing out of ocean acidification—but shade is temporarily protective while we do something more effective about carbon dioxide's overheating effects.

We were wrong to have made *Dieting* the primary strategy for the last few decades but, looking forward, it is still one of the ways to speed up an engineered cooling. Zero emissions tomorrow would allow natural processes to remove about half of the excess CO_2 over the next 28 years. We need to do the other half ourselves via *Cleanup*.



The 2023 Supplement

- Severe wind and hail (up 6X since 2008).
- Drought emigrants contaminate drinking water en route, spreading pandemics.
- Resource wars steal food from neighbors
- Civil wars turn into genocides.
- 90% human population crash becomes likely.
- *Very Dark Age*, as governments revert to the strong-arm kleptocracies of 8,000 years ago.

Figure 31. *Consequences,* if not headed off. With thanks to Arial, 2010.

But many climate scientists (at least the ones that write the big reports demanding concensus) still imply "Wait and see. Don't make any rash decisions. Stay calm and carry on." I do wish that there were minority reports looking at the extreme weather surge-and-stays and saying, "Time is precious. Let's not waste any."

By itself, emissions reduction is no longer a long-term strategy—it is simply inadequate to the task of backing out of the danger zone for collapse—but it can still speed up the drawdown of the excess CO_2.

There are, however, important reasons not to count on success with zero emissions. Working down to zero emissions is likely to require decades even in the leading countries, yet air mixing across borders means that we have to live with the global average. The slower achievement means that the 28-year time for natural decay by half needs a different focus—and urgently.

What is now the biggest climate challenge? It is not the fractional degrees of further overheating. It is heading off the collapse of civilization by quickly backing out of the danger zone. Time is indeed precious.

—to be continued—961 words

Climate's Big Picture

Design and prototype CO_2 scrubbers

WILLIAM H. CALVIN [9]

We are already halfway to doubling the CO_2 in the air. Net Zero would only take the CO_2 level (now 420 ppm, a 140-ppm excess above the pre-industrial 280 ppm) back down to what it was (350 ppm) in 1989. That is not enough.

It was 1985 when the continents began warming almost four times faster than the ocean surface; they had tracked each other in the 20th-century's ups and downs, until splitting dramatically after 1985. Thus 350 ppm, which would take 28 years to reach once continuing emissions were countered, is not an adequate target for backing out of climate's danger

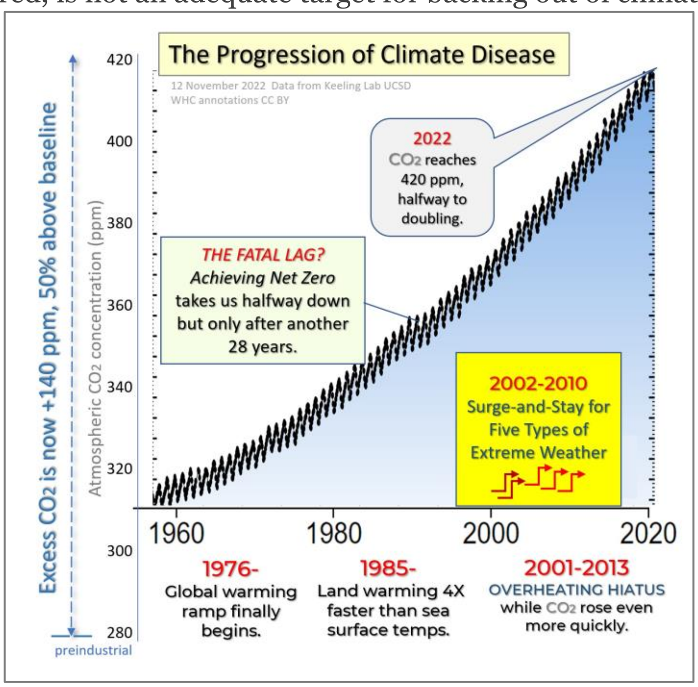


Figure 32. The Keeling Curve of monthly CO_2 measurements, compared to the progression of climate disease. The step-arrows are stalled hurricanes (beginning 2002), mega heatwaves (2003), 4x big forest fires (2006), 6x big windstorms (2008), and 3x big floods (2010). The sawtooth peak is the northern winter when growth is slowed and leaves are decomposing. While the southern hemisphere is doing the opposite, there is much less land surface there and so the northern effects dominate.

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zone. It will expose us to extreme weather for far too long, given how quickly economies can collapse and take big projects with them. Our aspirations have been half-measures, leaving us with an immediate need for stronger medicine.

Using only net zero tomorrow, nature's half-cleanup process would take at least 28 years—and even longer when we decrease emissions more gradually. Such a treatment plan would leave us trapped in the extreme weather danger zone for another century.

Judging from the archeological record of societal collapse, I doubt that civilization will survive that long. That makes a human population crash likely, probably followed by a thousand years of revenge killings over what happens during the "downsizing." Hotter summers is a misleading characterization of the risk we now face, thanks to allowing the excess CO_2 to build up over the last sixty years.

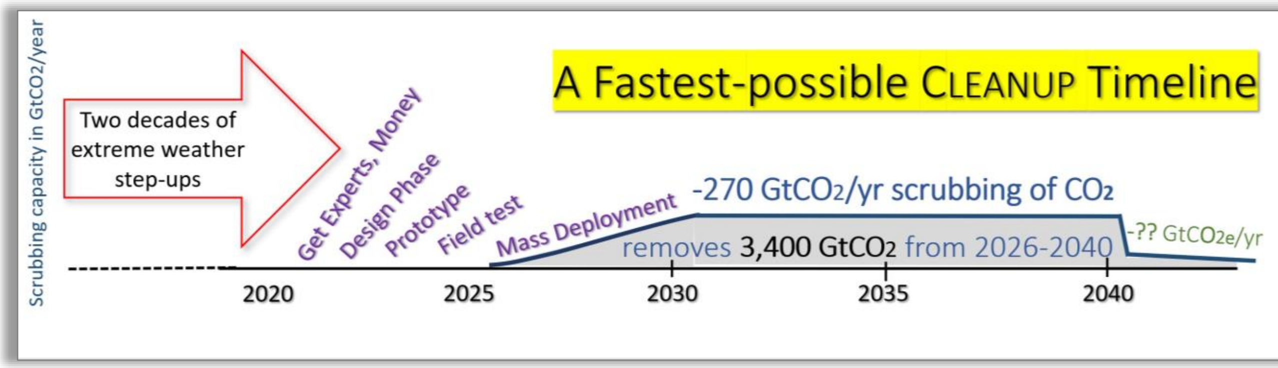

Figure 33. This is the fastest cleanup that I can imagine, very optimistic.
It includes first countering the continuing emissions, currently about 50 $GtCO_2e$/yr.

While there are good reasons to fear the world to come, we can try to manage climate impacts, building a future with workarounds and repairs. But climate hyperbole should be returned to the sports page where readers know to discount habitual exaggeration. Talk of "the climate endgame" is too reminiscent of wrap-up efforts to scare people into behaving better—but it can also render them passive, accepting their fate without making an effort.

While urgency is becoming emergency, there is nothing hopeless about our climate situation: we have not even tried any big-and-fast "Manhattan Projects" for climate repairs.

What are the current technical prospects for doing a cleanup? A 2018 review of eighteen carbon dioxide removal proposals revealed that none of them, scaled up to their claimed maximum capacity each year, could even counter the continuing emissions during the current year.

To start cleaning up enough of the legacy accumulation requires that we first implement enough annual sinking capacity to counter the continuing annual emissions. For CO_2 per se, that is now about 37 gigatons per year globally. Using extra CO_2 sinking to counter the annual methane and nitrous warming means we need to sink 50 gigatons of CO_2 each year before cooling could begin. Scrubbing 270 gigatons of CO_2 annually is about what will, within three decades, cool us somewhat and reduce the threat from extreme weather.

And where do we get enough scrubbers? We now need to convene a big design-and-test project with wartime priorities, analogous to the 1942-1945 Manhattan Project. I will briefly sketch a US-initiated project, but other major industrial countries will need to initiate similar big projects in parallel. We can save the international coordination, cost-sharing, and treaties for governance until later.

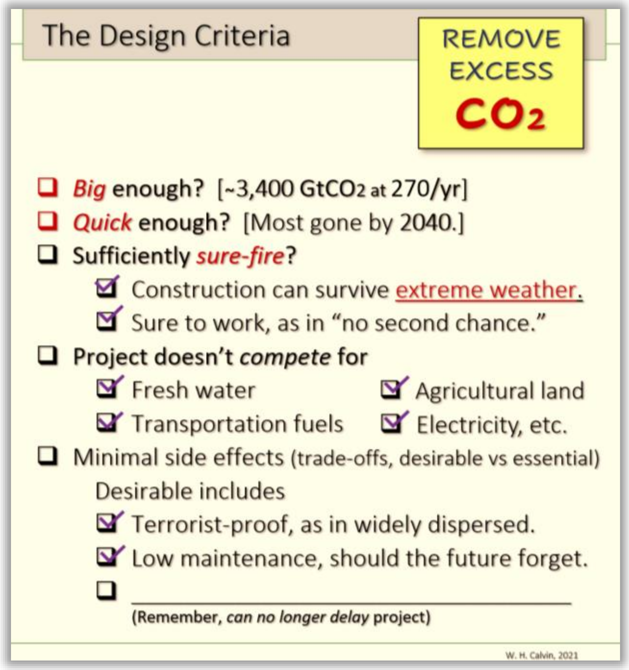

Figure 34. Design criteria for climate repairs.

At least in the US, the appropriations route will take too long. As a workaround for the promoted paralysis of the US government, I like to imagine the design project as a nonprofit that is initially led, to assert the public interest, by three state governors, ones with big environmental staffs to help select the international experts needed for the design consortium. The governors would select a project manager, perhaps a serial entrepreneur. For the first five R&D years, a finance committee of a dozen tech billionaires might suffice.

The *Governors' Design Consortium for CO_2 Cleanup* would also educate legislators as they proceeded—and then, within five years, present them with field-tested prototypes to run with, while development continued. Various governments could then mass manufacture and officially deploy. Someone with big-project experience needs to convince three concerned governors to undertake the task. Others might focus on starting a

Designing Shade Consortium. It will be needed to protect us and the project in the meantime.

What makes for a slippery slope is when extreme weather burdens the economy so much that institutions collapse. Then backing out of the danger zone with carbon dioxide cleanup projects becomes impossible to complete. "We are on a highway to climate hell, with our foot on the accelerator," the United Nations Secretary General, Antonio Guterres, said in 2022.

Because of the step-ups in five types of extreme weather between 2002 and 2010, climate urgency has become climate emergency. This is because the window of opportunity will close for big projects. Disaster relief, economic collapse, ruined states, and resource wars from extreme weather will soon make big projects impossible to finish in time.

Any doom-and-gloom appraisal should be prefaced with "Unless we quickly clean up the carbon dioxide accumulation, then …."

We have not yet passed all of the exits on the Freeway to Hell.

——the end—— 915 words

This is written to stand alone; no illustrations are essential. It works as one long essay with subheads or serialized into segments. The most recent draft is kept hidden from web crawlers at faculty.washington.edu/wcalvin/2022/ABC.pdf.

Comments to WCalvin@UW.edu. 725 9th Avenue, Box 2605, Seattle WA 98104. 206 328-1192, text 206.972.0030. CO_2Foundation.org | WilliamCalvin.org

Suggested reading

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Figures were originally created by the author for a possible revision of his 2019 book, *Extreme Weather and What to Do About It.*

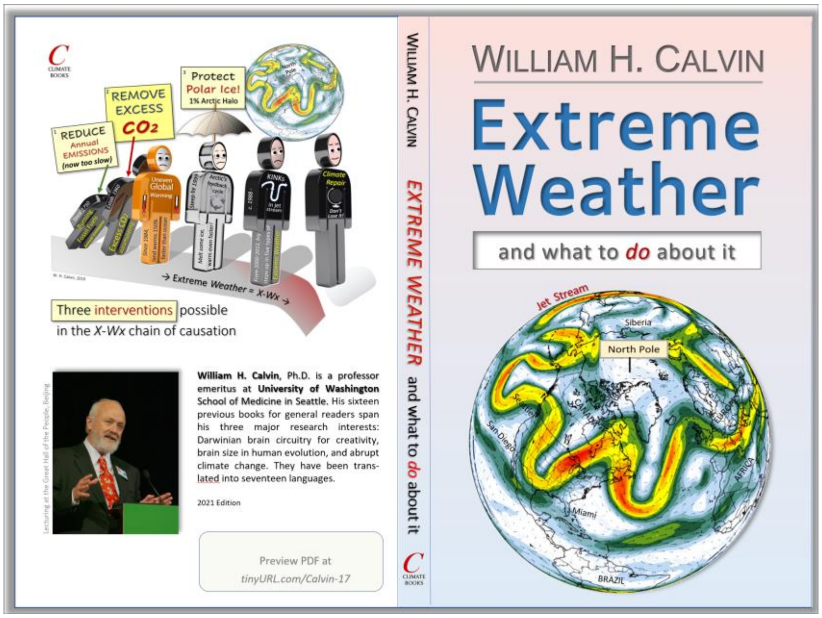

Figure 35. The earlier book.