

The Great Use-it-or-lose-it Intelligence Test

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To fit the magnificence of this setting in Beijing's Great Hall of the People, and the honor of giving the 2007 Sir John Crawford Memorial Lecture, it is well to have a subject of suitable proportions. I have chosen one of global size and urgent time frame: our climate crisis. We only have one future and one global climate—and now it looks as if we only have one chance to rescue our civilization from collapse and prevent a mass extinction of species.

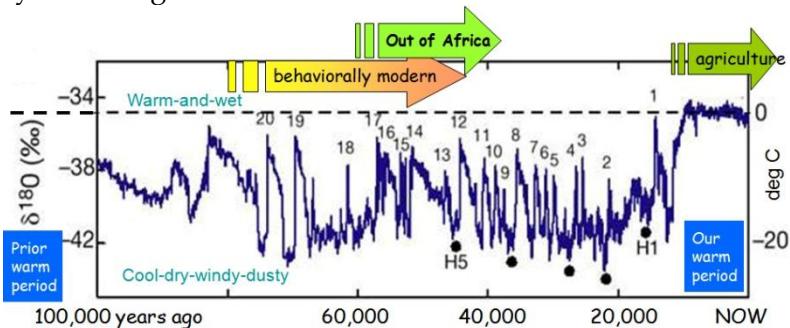
Unless you have been keeping up with climate science for the past twenty-five years, you likely do not know how serious the matter has become. The notion that we might slowly get into serious trouble by mid-century has been conveyed by the media and understood by at least some political leaders. But that scenario depends on somehow avoiding sudden shifts in climate in the meantime, instant

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setbacks at a time when we lack maneuvering room. An abrupt shift in drought area occurred in 1983 and we had a near-miss of a mass extinction of Amazon species in 1999.

It is easy to appreciate that one more degree of global warming will seriously reduce crop yields in the tropics, but in the words of climate scientist Claudia Tebaldi¹, “It’s the extremes, not the averages, that cause the most damage to society and to many ecosystems.” Even if you live where the average rainfall stays the same, there will still be more extreme weather such as floods and droughts. That they “balance out” will comfort no one.

To illustrate this, recall the old joke about the statistician who drowned in a lake known to be, on average, only one meter deep. This is, of course, a slander on statisticians who know better than anyone the variations in depth concealed by an average.



Here is the ice core record from Greenland (happily worm-free) which shows what our *Homo sapiens* ancestors had to deal with in the middle of the last ice age as our higher intellectual abilities evolved.

A moving average, created by worms stirring the ocean bottom, kept us from realizing that the “glacial pace of an ice age” was actually punctuated by very rapid (most of the way in five years) coolings and warmings. But since the changes only lasted centuries, their telltale sediments were churned sufficiently by the worms to make the record look

smooth. (When moving averages are used to plot securities prices, they too conceal the brief periods when fortunes were made and lost.)

These ice age abrupt climate shifts made the transition in only about five or ten years, the time scale of a drought but with global scope. Their immediate causes are not what concern us at present, but rather some additional routes to making a sudden change in global climate that involve rearranging the customary winds.

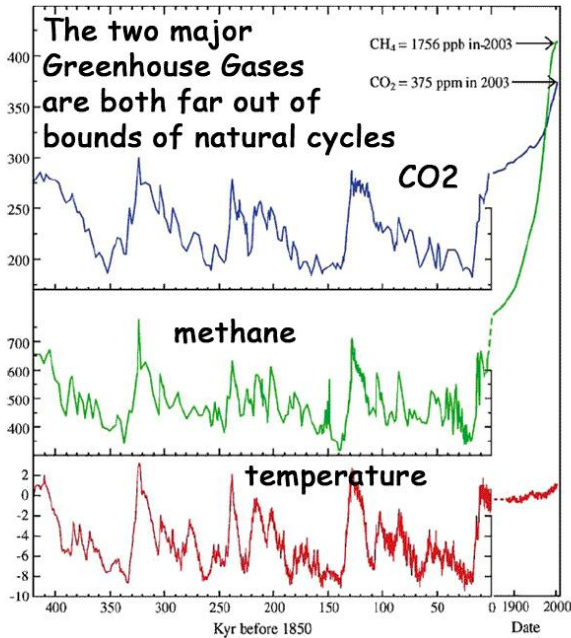
The Clock is Running

I am a medical school professor and one of the things we try to teach physicians is to remember that a clock is always running, that there is such a thing as being too certain but too late. “The doc who waits until dead certain of the diagnosis before starting treatment may wind up with a dead patient” reminds the medical student that textbook rigor may be out of place in a situation where irreversible damage may soon occur. Senior military officers are also taught to think this way, but few scientists are. I picked it up myself only because of talking shop with the neurosurgeons for several decades.

Politically, climate matters have already been “sent back for further study”—with action postponed—more often than was wise. We are now facing a planetary emergency where we have no time to search for the best or most economical treatment, nor can we wait for cap-and-trade schemes to evolve better practices. Even serious carbon taxes may be too slow. On the eve of a great war in 1940, President Franklin D. Roosevelt used the metaphor of a “four alarm fire up the street” that needed to be extinguished immediately, whatever the cost. That’s where we should be now in responding to our climate crisis.

Global Fever 101

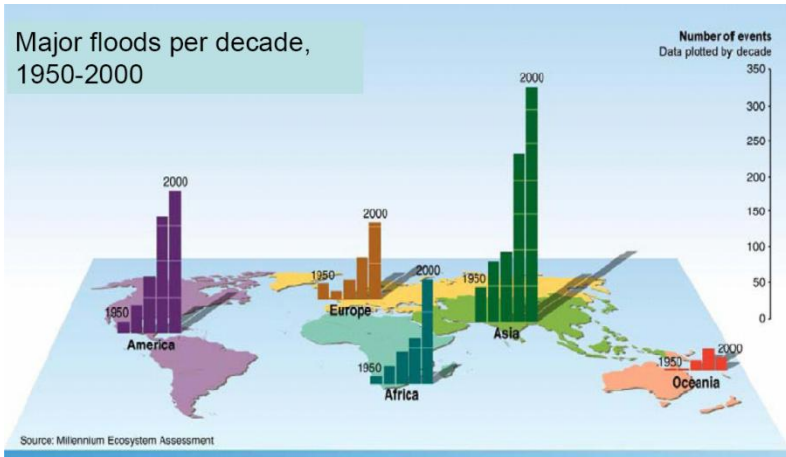
Briefly, the earth is overheating because of 1) the darkening of the earth's surface by irrigation and new greenery from high-latitude warming, which captures visible light that would otherwise be reflected back out into space, and 2) the greenhouse gases that are growing an extra blanket of insulation around the earth, capturing infrared heat that would otherwise escape into space. Together, they rearrange the winds and rains.



It is often claimed that our climate troubles are just “natural cycles,” about which we can do nothing. Neither is true. We now have records of air composition that go back 800,000 years, enabling us to see the largest of the natural cycles. Both CO₂ and methane go up during the warm periods that interrupt the ice ages, then back down during

cooling. Since about 1850 (expanded scale at right), both have soared (CO₂ by 37 percent, methane by 130 percent) and are now far outside their natural range. Temperature is beginning to follow. It would be much higher already except for the reflective haze from sulfates and ash, which masked a third of the expected rise in temperature.

It is much easier to see the signature of climate change in records of wind, rain, and fire. Each decade from 1950 to 1999 saw a significant increase in major floods, and this was true worldwide—showing that it wasn't just local idiosyncrasies that produced the problem.

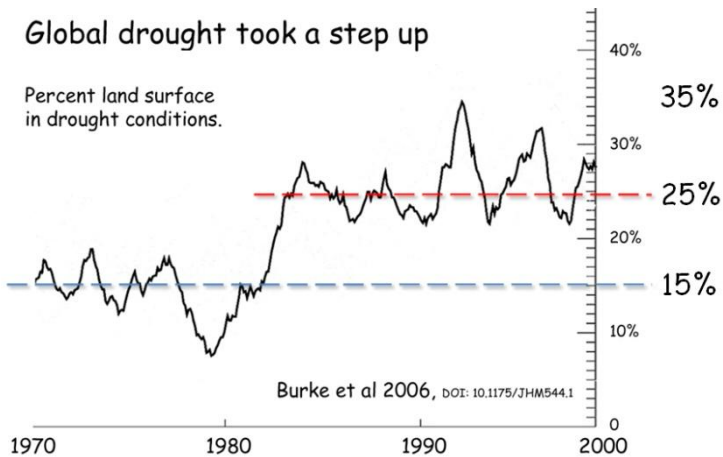


There's a consistent 50-year upward trend in every region except Oceania.

The same picture emerges when looking at major forest fires. Moving in lockstep, for both floods and fires, is global climate change.

While floods and fires have steadily increased over the fifty years, drought shows signs of even more abrupt stepwise change. Some of the earliest warning came from Perth's reservoir inflows, which dropped in 1975 to half of the prior average. In 1997, this runoff took another step down to a third. Both were within a year of a big El Niño.

Not included in the 2007 IPCC reports is the recent analysis of global drought. In the 1970s, only 15 percent of the global land surface was in drought at any one time. By 1983, this had jumped to 25 percent. It occurred at about the time of the 1982 El Chichon volcanic eruption and the large 1982-1983 El Niño. Whether a move is temporary or a new baseline can only be judged in retrospect. There have been fluctuations to 35 percent but the new baseline is 25—which is an enormous two-thirds expansion of the 1970s drought area. And it only took a year to make the shift.

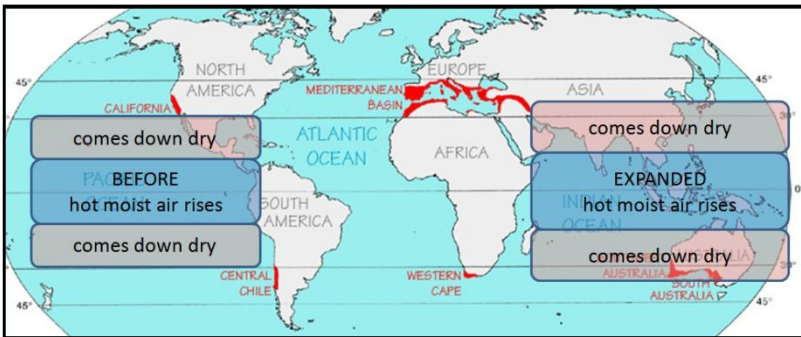


So where is all of this new drought? Much is adjacent to the dry bands of the tropics where the air that ascended in near-equatorial thunderstorms comes back down, minus its moisture, to create the characteristic deserts such as the Sahara and Kalihari. The zones of Mediterranean climate are just above 30° from the equator and, while only on the western shores of a continent, they illustrate the problem of expanding tropics.

They, like the adjacent deserts between 22° and 30°, lack rain in the summer. But the westerlies manage to push some

low-pressure systems from offshore through Mediterranean climate zones in the winter, giving them their characteristic combination of winter rain and summer sun.

The desert border has already moved a few hundred km farther away from the equator. Not only are the countries around the Mediterranean suffering from a drier climate, but so is southern California, southern Australia, and the bottom of Africa. Central Chile suffers especially during a La Niña.

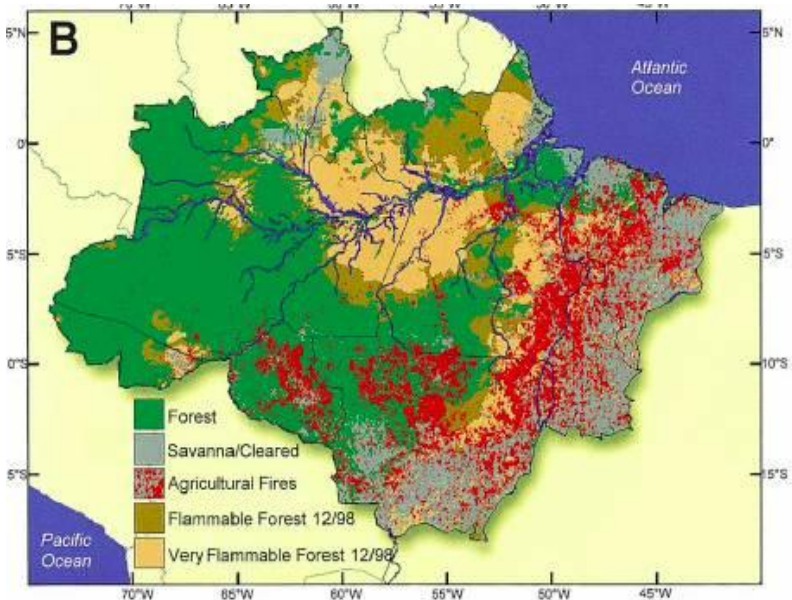


At least by the global drought measure, an abrupt climate change has already occurred from global warming, making our fixation on long-term, slowly developing solutions seem especially shortsighted. It would be like an emergency-room physician talking to a patient about losing weight instead of focusing on the new chest pains that could be the beginning of a heart attack.

Exit Amazonia?

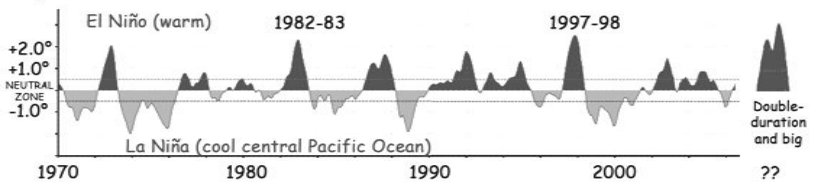
The Amazon Basin is surprisingly vulnerable, even without all of the slash-and-burn land clearing for new agricultural fields, even without the seasonal burn before planting. Global warming is expected to change the rainfall patterns enough so that plant succession after a big fire will not advance beyond grass and brush.

This need not take all of the century to slowly occur. A big fire could happen at any time, given another big El Niño that lasts long enough to dry out the Amazon. The fire vulnerability map shows the conditions at the end of the 1997-1998 El Niño, which lasted about a year.



Just after 1998 El Niño. Nepstad et al., *Forest Ecology & Management* 154, 2001

We have seen longer El Niño's but they were not also big. The big ones (more than a 2°C temperature rise in the central Pacific) may be new, a consequence of global warming.



No one yet knows what sets up a big one, let alone controls its duration. With only 10 to 15 years between past examples, we might soon see another big one and, given the stepwise changes associated with the three previous ones, we might also experience another step up into a worse climate.

The possibility that I find most appalling, however, is what would happen should a big El Niño endure for an extra year. The fires in Southeast Asia and in the Amazon Basin in 1997-1998 were bad enough; with a double-duration El Niño, we could lose major parts of two of the world's three major rain forests in the tropics.

The global warming consequences would be severe. First, the excess CO₂ in the atmosphere would go up 40 percent in a few years². Second, given all of the missing leaves, the annual CO₂ emissions from fossil fuels would become 50 percent more effective in raising the temperature each year thereafter. Third, we would lose about half of the plant and animal species in those rainforests, both from direct mortality and loss of habitat. It would be the first anthropogenic mass extinction. In 1999, we had a near-miss on this catastrophe as the El Niño quit just in time in 1998.

As we continue to accelerate the use of fossil fuels (emissions are up 35 percent since 1990, exceeding even the

² Excess CO₂ is that above the preindustrial concentration—say the 280 ppm maximum during recent warm periods of the ice ages. We are currently above 380 ppm, a 100 ppm excess, and a Big Burn of the Amazon and Borneo rain forests would add another 40 ppm. Forests take many decades to grow back but Amazonia will become stuck at the succession stage of grass and brush, so its carbon becomes a “permanent” addition to the air. Indeed, given our half-century time scale, few forests will re-grow enough after fire to balance their loss. All such fires are setbacks for us and the species likely to go extinct..

pessimistic business-as-usual scenarios used in climate models), that's the kind of catastrophe we could trigger.

Threats to the Ocean Food Chain

Life in the oceans has also been in trouble and it's not just the fisheries decline as there has been a decline in plankton as well. The heating of the near-surface layers during the 1982-1983 El Niño reduced sea life around various Pacific islands because the heat killed off much of the plankton at the bottom of the food chain, which then devastated the fisheries, the shore species, and the birds. The 2005 hurricane season in the Caribbean was associated with enough days of excessive temperature to kill many coral reefs, even down to a 70 m depth in the Virgin Islands.

Ocean acidification of 0.1 pH unit occurred in the 20th century and the forecast for this century is for another 0.3. Thus fossil fuel emissions have a dual effect: the usual one from over-insulating the earth, and a second direct effect on the acidification of the near-surface oceans as they absorb CO₂ from the air bubbles buried under crashing waves.

There was a brief respite in the warming of most of the world's oceans in the early 1990s from volcanic sulfates injected into the stratosphere. Even when heat waves are moderated by reflecting more sunlight back into space, the pH effect of the continuing emissions of CO₂ can get us into serious trouble from damaging the bottom of the ocean's food chain.

Undermining Ice Sheets

Sea level was more than 6 m higher than present during the Eemian warm period about 125,000 years ago. Greenland's ice was particularly vulnerable then, with summer temperatures at about what 1.6°C of global fever (we are now at 0.7° above preindustrial global mean temperature)

would produce there now. The West Antarctic Ice Sheet likely contributed some more water when undermined by the rise in sea level from Greenland's collapse. In Greenland, melt water falling down deep cracks carries heat to the bottom of the ice sheets, creating rotten ice that allows the ice sheet to slip downhill into the ocean more quickly. The new icebergs instantly raise sea level.

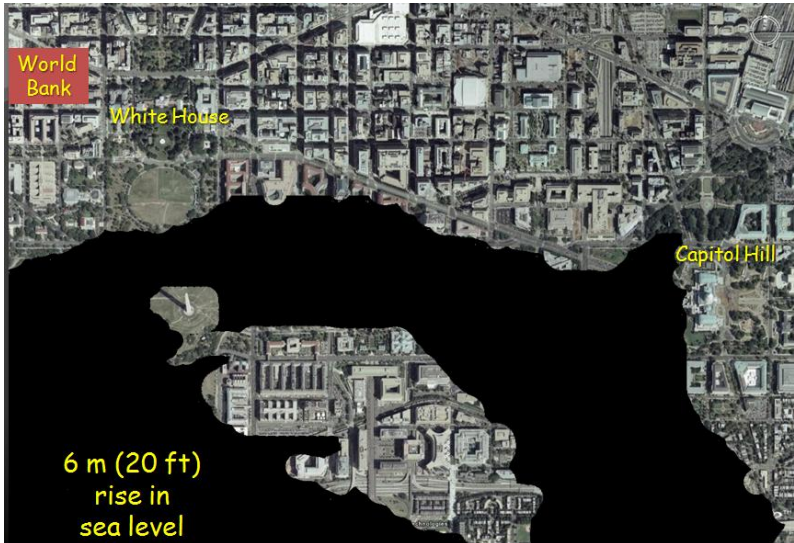
Sea levels may rise more quickly than what the drip-by-drip 2007 IPCC models indicate (about 0.3 m this century and even that is mostly from thermal expansion of the existing oceans). Some glaciologists worry about a rise of 2 to 3 m this century. Eventually about 50 m should be seen for a 3°C rise, judging from the 4 million year history of global temperature and sea level.

Let me stick to the first 6 m rise, which is about the height of a two-story beach house. Along the East and Gulf Coasts of the U.S. with their shallow slopes, that can mean an inundation reaching 150 km inland in places, with 15 million people displaced in Florida alone. But most of the misery will come from river deltas whose fertile soils and plentiful water support high populations at present. Half of Bangladesh will be underwater when sea level rises 6 m, creating 70 million climate refugees on their side of the Ganges Delta alone. It's a similar situation for all of the river deltas in Southeast Asia and China.

As with more immediate refugees from the droughts in the Mediterranean climate zones, where will such climate refugees go? What will be the reaction when they cross borders in great numbers? What country will try to take over the resources of a neighbor, pushing its inhabitants out into a third country?

The Four Horsemen of the Apocalypse tend to be featured on such occasions: famine, pestilence, war, and death from genocides. The latter will have a long-lasting

legacy: the downsized populations will all hate their neighbors for good reasons. It seems a situation well worth avoiding with vigorous action now.

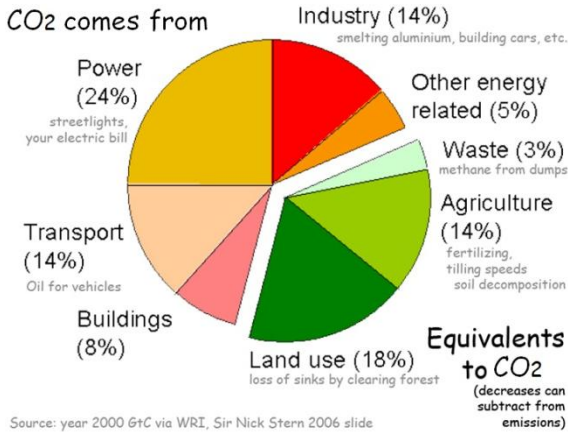


The Origins of CO₂ and its Equivalents

Per unit of useful energy, coal produces the most CO₂, natural gas less than half as much, with oil in the middle. Once it gets into the air, CO₂ is slow to get out, with half remaining several centuries later. And because the ocean's capacity to absorb it is limited, a fourth of the excess CO₂ may still be around in a thousand years.

Methane from natural gas and low-oxygen decomposition is twenty times more potent as heat insulation, once it gets into the air. So we talk of its "CO₂ equivalent" as being twenty times as much. But methane is not equivalent in other ways, as half of the methane released into the atmosphere this year will have disappeared about six years from now. Stopping the leaks from natural gas pipelines (1 to 4 percent of what is carried) will improve things almost

immediately, whereas CO₂ declines will take centuries unless we remove it from the air to reverse climate change.

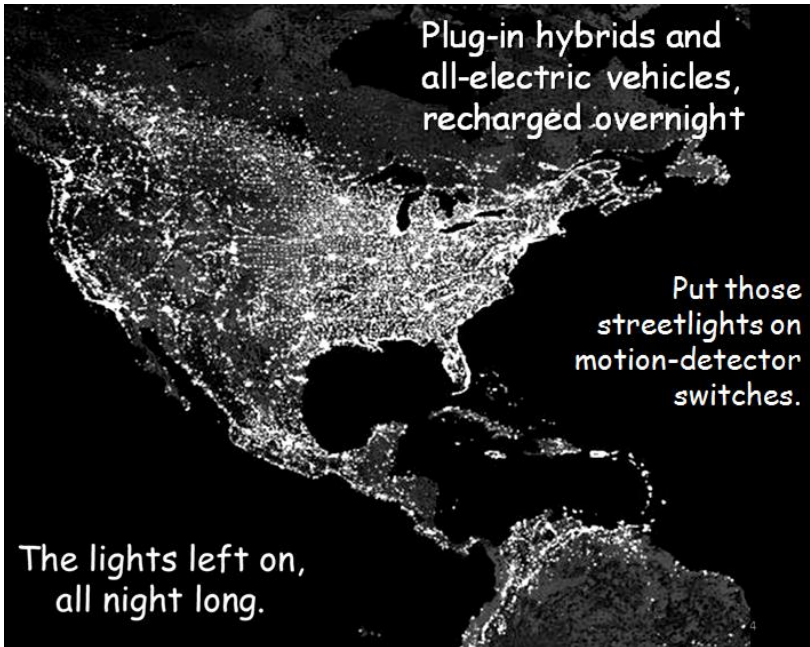


The pie chart of the uses which create CO₂ and CO₂ equivalents shows that fossil fuel uses are about two-thirds of the total. Transportation uses (mostly oil) are 14 percent of the pie—but so too is agriculture, what with feed lots, fertilizer, and tilling the soil. Even more startling to me was the 18 percent slice for changes in land use, some of which is urban sprawl but much of which is land clearing for marginal agriculture.

So while burning fossil fuels is two-thirds of the problem, much of the rest is associated with agriculture. Certainly, many of the opportunities to fix our global climate lie in the agricultural sector because there is so much “low-hanging fruit” there—irrigation, tilling, feedlot, and fertilizer practices being what they currently are.

For transportation, we need to replace petrol with electricity, either via batteries or electricity-generated hydrogen fuel cells—or simply compressed air, driving a piston engine with injections of high-pressure air. I expect that the Air Car will be a popular choice in the tropics because of the free air

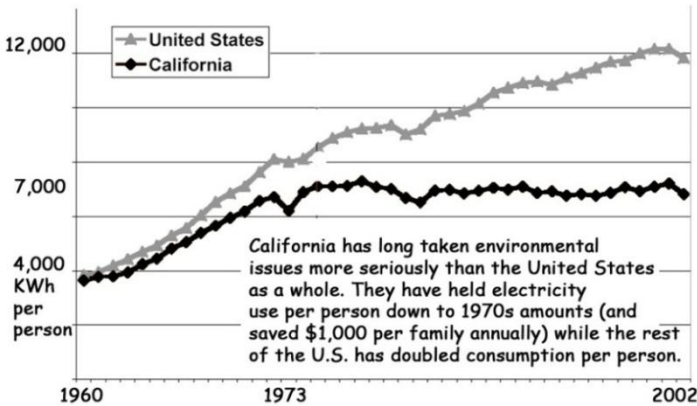
cooling for the occupants (the vehicle will also be warm in the early morning after overnight recharging of the tanks). India's largest automaker expects to have 6,000 taxicabs running on compressed air in 2008.



Electricity and its Uses

In the U.S., 86 percent of our total energy use comes from fossil fuels. Only 14 percent is clean, mostly from hydro and nuclear.

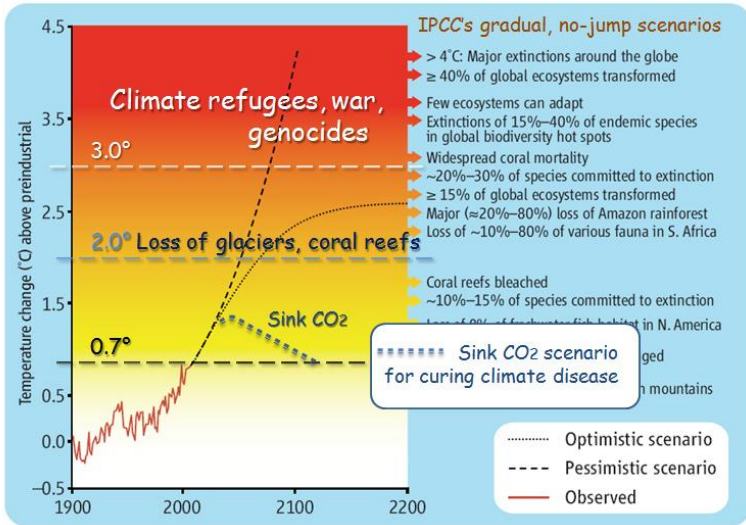
If we focus on electricity generation, then we are 32 percent clean. Thanks to 35 years of expanding nuclear, France's electricity is 91 percent clean, and next door in Switzerland, it is 99 percent clean (half hydro, half nuclear). Next door in Germany, electricity is only 42 percent clean. In many countries such as India, China, and the UK, less than 25 percent is clean.



Regional variations neatly show the role of government energy policy, even within the U.S. Per person electricity consumption in California is only half that in Texas and New York State is almost as thrifty. Even more impressive is that California has kept that figure from growing for 35 years, at a time when many states doubled per capita consumption. So part of the solution is simply copying the practices of the successful (California initially set standards for appliance efficiency and codes for new housing). Unfortunately, that now isn't fast enough.

The Window of Opportunity is Rapidly Closing

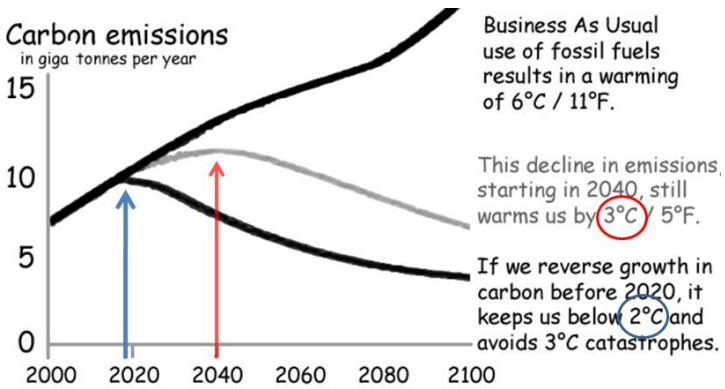
At a time when architects are thinking ahead to more efficient buildings and power planners are extolling the virtues of "renewable energy," the climate modelers have discovered that long-term planning will no longer suffice. Our fossil fuel fiasco has already painted us into a corner such that, if we don't make substantial near-term gains before 2020, the long-term is pre-empted, the efforts all for naught.



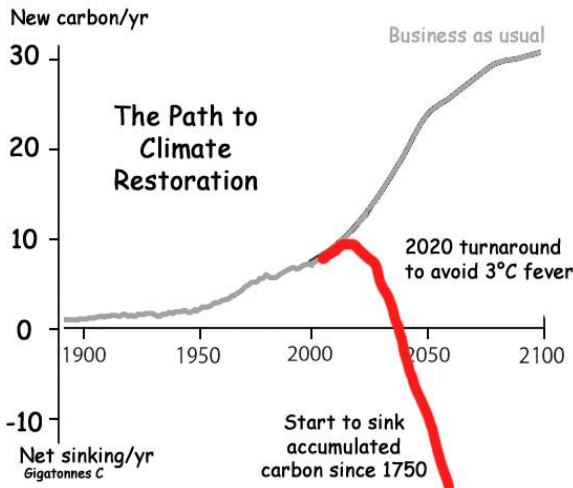
adapted from *Science*, 23 November 2007 news article

If the world keeps on with Business As Usual expansion of energy use, the world will be about 6°C warmer by the end of this century (the interior of continents will warm about twice as much, as will the high latitudes). If the world manages to get its growth from clean sources while not increasing fossil fuel uses, this so-called “stabilization” in emissions would still leave us adding carbon to the atmosphere, merely at a constant rate each year. This is the most minimal of targets and hardly deserves being called stabilization since climate change will continue getting worse.

If this limitation of emissions is achieved by 2040, the global mean temperature goes up about 3°C. If it is achieved by 2020, we might be able to hold it to 2°. The consequences of a 2° fever are bad but nothing like the world of climate refugees that a 3° fever will create.



Furthermore, such a minimal goal will do nothing to relieve our climate problems. It takes more than stopping new emissions. It requires actually removing the CO₂ from the air. The 2007 IPCC report didn't even consider such scenarios but I have sketched one out below.



The zero-crossing in 2040, where remaining fossil carbon emissions are offset by new carbon sequestration, might be called climate stabilization—except for the delayed warming (0.6°C in a century) and the continuing vulnerability to the

big one-off events such as burning down the rain forests. It is only when we haul the CO₂ down to levels last seen in mid-20th century—and with it the fever—that we may escape the excess exposure to such big events. That might be a better goal to aspire to, and a better use of the term “climate stabilization.” It is about time we started thinking in terms of a cure for climate disease, not just buying time.

Taking Carbon Out of Circulations

Nature removes atmospheric carbon by photosynthesis and by “weathering” rock. The latter counts on the million year time scale, but we need something quicker.

We are more familiar with green leaves but the floating microalgae in the oceans—called phytoplankton and usually seen as unwanted scum on the walls of an aquarium—do more than half of the world’s conversion of CO₂ into O₂. Which is fortunate, because of the aforementioned fire hazard from stronger, hotter, and drier winds in the coming decades. Planting more trees cannot be relied upon to keep the carbon out of circulation.

The ocean depths are an excellent carbon storehouse as those waters are rarely “ventilated” to the atmosphere except on the million year time scale. What do we need to do to sequester more carbon on the decade scale?

Algal reproduction is usually limited by nutrients. Long-lasting blooms occur near the mouth of a river (or sewage outfall). Episodic blooms tend to occur via wind-driven upwelling of deeper waters, bringing some of the falling nutrients back up to the top. However, unless there is also enough iron in surface waters, there will be no bloom. Iron naturally arrives via dust blown into the oceans. Stimulating or prolonging algal “blooms” via iron fertilization has been investigated for more than a decade.

Beginning about a week after an algal bloom starts, a zooplankton bloom appears, a mix of lots of little animals, some of which will grow into bigger animals if they avoid getting eaten in the meantime. Some little animals such as the microsnails, diatoms, and coccolithophores grow shells of calcium carbonate. When they die, the shell sinks into the ocean depths. Some become limestone. Ocean acidification threatens to interfere with making such shells.

A second way that the primary production's carbon is sunk is via fecal pellets of larger animals that graze on the plankton. Many species are simply too small, their feces merely mixing right back into the nutrient soup of the near-surface ocean. Salps are large enough to produce fecal pellets that are compact and heavy enough to sink into the ocean depths before disintegrating. Filter-feeding whales are even better, though greatly expanding their numbers would be a century-long project because of their slow lifespan.

The important thing is to reduce atmospheric CO₂ concentration. Just as taking fossil carbon out of storage has increased the amount in circulation between the atmosphere and the land and ocean surface, so we can take organic carbon out of circulation in deep landfills. An important lesson comes from the comparison of the muddy waters of the Amazon and those of the Himalaya monsoon runoff through Bangladesh and India. Most of the organic carbon that settles out on the Atlantic continental shelf decomposes and contributes its CO₂ to the atmosphere, but only about 30 percent of the Himalaya monsoon runoff decomposes as the end of season runoff effectively caps the peak runoff before it can decompose². About 70 percent is safely sequestered. Only the top 10 cm remains exposed to circulating seawater with oxygen. In a similar manner, we might bury biomass in sealed landfills and create a cascade of managed settling

ponds for the slower muddy rivers. This would also save soil for future generations.

The Climate Optimist

When most people first come to realize our peril from climate change, they are unable to imagine how we might get ourselves out of the mess. Sometimes failure of imagination does indeed determine our future, but thanks to our accumulated intellectual achievements, a Third Industrial Revolution is likely coming, one that will replace fossil fuels and create nonpolluting agriculture.

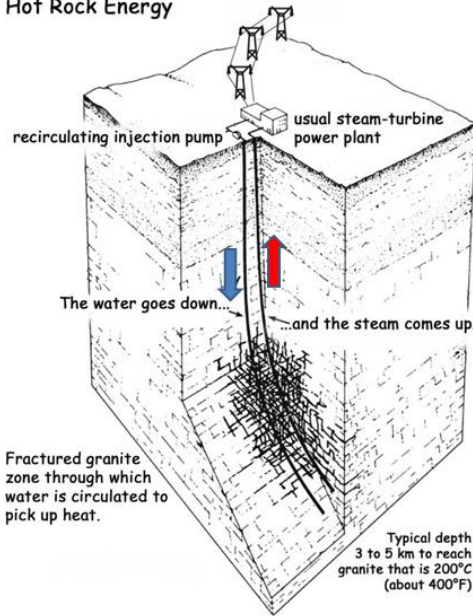
The problem for an optimist, however, is time. We have been painted into a corner by our accelerating use of fossil fuels in the last fifty years. Now we are forced to act quickly to produce major accomplishments by 2020. So let me sketch out a near-term agenda using existing technology that is capable of heading off the 3° future fever.

Our enthusiasm for long-term thinking is, sad to say, short sighted given the 2020 emergency. Rapid transit requires decades to build. City planning helps only in the long term, not much in the near term. I'm inclined to put the big money elsewhere for now. What we do for 2020 will reframe the problem, and new science and technology by then will hopefully show us a better long-term path.

All-electric vehicles and plug-in hybrids will shift the transportation sector's energy needs from oil to whatever produces the local electricity. This need not mean batteries on board as the electrical power can be used to create some other intermediary fuel, hydrogen for fuel cells or compressed air for driving the pistons of an air engine. This will get rid of much of the CO₂ from petrol. Even if the electricity comes from coal, there's a large gain because of size efficiencies and avoiding the waste of idling internal combustion engines in traffic jams.

It's obvious that we need to ban new coal plants. In my opinion, we must start cloning nuclear and geothermal power plants at a rate sufficient for new demand and for shutting down old coal plants in the next decade. Anything that cannot reproduce at the gigawatt per week level will need to take a back seat to the more sure-fire methods for cleaning up half of the dirty electricity in the next decade. Not even the largest solar and wind installation comes close to a gigawatt, and adding a gigawatt of capacity every week from them seems decades off.

Hot Rock Energy



- Deep geothermal ("heat mining") pumps down water, gets steam back up to run steam turbine.
- No pollution, small footprint, steady output.
- Also suitable for developing countries.

Hanging over all of these ideas is the global aspect of CO₂. We must make sure that developing countries do not modernize by burning their own coal and oil. That means helping them with solar thermal or geothermal installations which run steam plants, in return for binding agreements not to add fossil carbon to the air. It means providing them

with technology suitable to local resources, not importing photovoltaic panels, batteries, and fuel cells with scarce foreign currency earned through exports.

As I see it, we already have most of the technology to make the low-carbon transition. The science is in good shape too, developing considerable momentum. The major challenge is the fast response needed from economic and political leaders.

Arming for a Great War

Preventing the 3^o fever is the Great Use-it-or-lose-it Intelligence Test. And we are dealing with the time frame used centuries ago by Edmund Burke when he said, “The public interest requires doing today those things that men of intelligence and goodwill would wish, five or ten years hence, had been done.”

We are already in dangerous territory and have to act quickly to avoid triggering widespread catastrophes. The only good analogy is arming for a great war, doing what must be done regardless of cost and convenience.

If you haven't already, I'd suggest reading

Jared Diamond. *Collapse: How Societies Choose to Fail or Succeed*. Viking, 2005.

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Joseph J. Romm. *Hell and High Water*. William Morrow, 2007.

Robert Henson. *The Rough Guide to Climate Change*. Rough Guides, 2006.

Mark Lynas. *Six Degrees*. Fourth Estate, 2007.

Brian Fagan. *The Long Summer: How Climate Changed Civilization*. Basic Books, 2004.

Tim Flannery. *The Weather Makers*. Atlantic Monthly Press, 2005.

Ross Gelbspan. *Boiling Point*. Basic Books, 2004.

Elizabeth Kolbert. *Field Notes from a Catastrophe*. Bloomsbury, 2006.

James Lovelock. *The Revenge of Gaia*. Penguin/Allen Lane, UK, 2006.

George Monbiot. *Heat: How to Stop the Planet Burning*. Penguin/Allen Lane, UK, 2006.

Fred Pearce. *The Last Generation: How Nature Will Take her Revenge for Climate Change*. Eden Project Books, UK, 2006.

A. Barrie Pittock. *Climate Change: Turning Up the Heat*. CSIRO, Australia, 2005.

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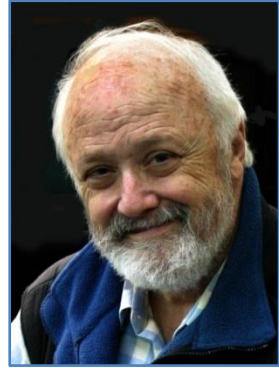
Spencer R. Weart. *The Discovery of Global Warming*. Harvard University Press, 2003. Updated version at www.aip.org/history/climate.

¹ Claudia Tebaldi et al, "Going to Extremes," *Climatic Change* (December 2006). See www.ucar.edu/news/releases/2006/wetterworld.shtml.

²Valler Galy et al, "Efficient organic carbon burial in the Bengal fan sustained by the Himalayan erosional system," *Nature* 450(15 November 2007)407-410, at [dx.doi.org/10.1038/nature06273](https://doi.org/10.1038/nature06273).

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(b.1939) is a professor at the University of Washington School of Medicine in Seattle. He has written fourteen books for general readers. His 1998 cover story for *The Atlantic Monthly*, “The Great Climate Flip-flop,” was the first major magazine article on the now-familiar subject; it grew out of a long-standing interest in abrupt climate change and how it influenced the evolution of a chimpanzee-like brain into a more human one. He expanded on these topics in *A Brain for All Seasons: Human Evolution and Abrupt Climate Change*, which won the 2002 Phi Beta Kappa Book Award for Science and the 2006 Walter P. Kistler Book Award.



A Brief History of the Mind: From Apes to Intellect and Beyond (2004) addresses what led up to the “Mind’s Big Bang” about 50,000 years ago, a creative explosion compared to the very conservative trends in toolmaking over the previous 2.5 million years. That span featured several million-year-long periods without much progress – despite the growth in brain size.

Calvin’s neurobiology research interests primarily concern the neocortical circuits used for those aspects of consciousness requiring detailed planning and speculation. He collaborated with the linguist Derek Bickerton to write *Lingua ex Machina: Reconciling Darwin and Chomsky with the Human Brain* (2000) about the evolution of syntax.

Following studies in physics at Northwestern University, Calvin branched out into neurophysiology via studies at MIT, Harvard Medical School, and the University of Washington (Ph.D., physiology and biophysics, 1966). For twenty years, he talked shop every day with the neurosurgeons, then moved on to the biologists, psychologists, anthropologists, linguists, psychiatrists, and climate scientists. His most recent book is *Global Fever: How to Treat Climate Change* (2008).

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