

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

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Let us start with the polar bear, whose population crash will be revisited by camera crews every summer until extinction in the wild finally occurs. Clever as they are, bears probably do not have the mental capacity to imagine what's coming—and thus cannot worry about their peril.

Neither can the great apes. Most have the technical ability to improvise simple tools, but they probably aren't up to proto agriculture—say, using fire to clear the brush in their hunting grounds so grazing animals will come to feast on all the new grass next season, which we started doing 80,000 years ago. Nor can they cut down the forests and plow the soil—which is what started global warming 8,000 years ago. Like the polar bears, apes are not likely to foresee their own death or worry about the extinction of their species. Nor, of course, are they capable of creating the worldwide environmental degradation which threatens them—and us.

Higher Intellectual Functions

What makes humans so special is that our ancestors learned to juggle many symbols and plans for action, as when we speak a long sentence such as “Who did what to whom.” We can say, “I think I saw him leave to go home,”

three sentences nested inside a fourth. We can make contingent plans: “We'll go to the country this weekend—but if it rains, we'll go to the movies instead.” We can juggle novel combinations and judge them for how well they hang together, as in games and logic. We take great pleasure when things hang together particularly well, as in harmony or those eureka moments as we solve a crossword or jigsaw puzzle.

It was a big step up to the flexibility and creativity that we call “higher intellectual function.” But there hasn't been much time for natural selection to get the bugs out. The bugs provide backdoors that allow a certain type of marketing expert to exploit us.

From behavioral economics, we know that there is an irrational overlay on our creative rationality. Status quo bias, the tendency to keep doing what you've always done, is often stronger than the rational arguments for changing course. People have a tendency, when faced with too many choices, to decide not to decide. People “endow” their possessions and paychecks with inordinately high value, simply because they possess them. We feel the pain of a loss more acutely than the joy of a gain – that's why future gains are hard to balance with the loss of present-day spending.

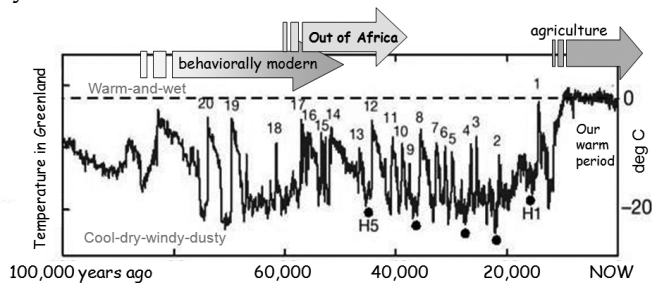
Enter the Modern Mind

A survey of the archeology will show you that the modern mind only goes back about 50,000 years. Whatever the brain enlargement was about, it is hard to find evidence of us getting smarter and smarter along the way. There were several million-year-long periods where tool making showed little progress, despite a lot of brain enlargement.

It wasn't until 200,000 years ago that people appeared who looked like us (anatomically modern *Homo sapiens*) but it took another 150,000 years before there were many people who thought like us. The Creative Explosion, about 70,000 to 40,000 years ago in the middle of the last ice age, happened without any further change in brain size. It may be something like an old

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computer getting an upgrade to its operating system.



Whatever it was, our enlightenment occurred during the last ice age when climate was very unstable, flipping in only a few years from cool-and-dry into warm-and-wet. Then, a few centuries later, right back down again. The last such big flip was about 11,500 years ago and, with a minor exception 8,200 years ago when a mega-flood disrupted the ocean circulation, climate has been remarkably stable since then.

Agriculture and Climate Stability

It seems to have taken 2,000 years of climate stability for plant and animal domestication to finally succeed. We were likely smart enough for such endeavors by 50,000 years ago but when some smart farmer was attempting domestication, a climate crisis would come along and all would be lost.

By 9,500 years ago in China, they domesticated pigs, silkworms, rice, and millet. About the same time, the Levant developed their own suite of wheat, barley, chickpeas, sheep, and goats. About 5,500 years ago in the Americas, two regions independently domesticated their own suites, from which we get two of our modern staples, maize from Mesoamerica and potatoes from Andes-Amazonia.

The Climate Stimulus for River Civilizations

The next big step up occurred about 5,200 years ago when the Sahara lost its grass. Before then, the summer afternoons were hot enough in the pluvial period to attract enough monsoon rainfall to grow grass (and grazing animals and lions and hunters). But when grass no longer held the soil in place, it blew away and we got the modern Sahara and Arabian deserts.

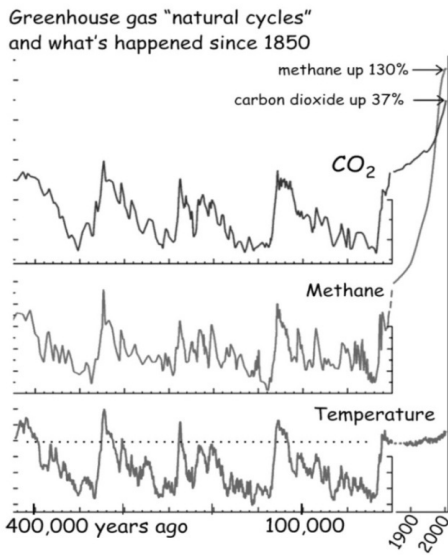
This transition made large-scale irrigation necessary to maintain the agricultural populations in the Nile and Tigris-Euphrates valleys. The taxation system to do such things required record keeping and that, about 3200 BCE, resulted in the invention of writing—which changed everything.

Flooding the fields was their mass irrigation method, although the ancients also buried refillable clay jars near plants which slowly leaked water. It was only in the last century that we added the impact sprinkler. The least wasteful of water (and fertilizer) is our modern drip irrigation but, even in the U.S., it is only 7 percent of all irrigation, with the wasteful sprinkler and flood-the-fields methods accounting for 93 percent of the water for agriculture. This will surely change with the water shortages predicted for coming decades as climate change shifts into high gear.

Global Fever 101

Briefly, the earth is overheating because of 1) the darkening of the earth's surface by irrigation and new greenery, 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 rainfall—and it is their extremes which do the damage to our societies, not the new averages.

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 pollution from sulfates and ash that masks a third of the expected rise in temperature).



Agricultural Impacts on Climate Change

For modern climate change, there are some unfortunate aspects of modern agricultural practice. We tend to focus on methane from feed lots, nitrous oxide from fertilizers, and tilling the soil serving to accelerate decomposition. But let me focus on some more general effects that are less known.

Water vapor accounts for two-thirds of the greenhouse effect. Humidity increases with global fever because more water evaporates from warmer oceans. But we have also put additional water into the atmospheric circulation. The extra humidity from the reservoirs and the wasteful irrigation practices serves to warm the planet.

Unlike the light-colored surfaces they replace, the greenery and moist soil is dark and so the planet doesn't reflect as much sunlight back out into space. This extra heat warms the planet.

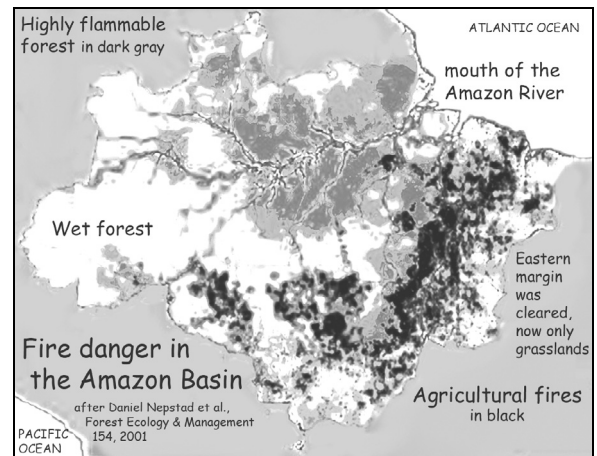
The same is true of soot from agricultural fires, used to clear the fields each season before planting. True, the CO₂ that comes from burning off weeds and corn stalks is recaptured by the next crop (provided a drought doesn't prevent it) but the soot in the air absorbs heat from the sunlight and then warms the air around it. This raises the dew point and often reduces rainfall downwind. You can see it looking down on Amazonia, a hole in the clouds through which you see the agricultural fires. The same rainfall

reduction is also seen downwind of urban areas burning a lot of coal and oil.²

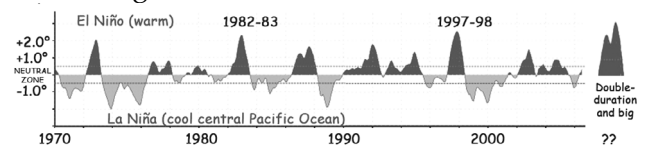
Exit the Amazon?

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.



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. But with only 10 to 15 years between past examples, we might soon see another big one.



² The finer particles of black carbon, when inhaled, cannot get back out. Surgeons report that by middle age, our lungs are darkened, compared to the pink-white lungs of a newborn.

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 years³. 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.

What the IPCC Reports Leave Out

The one-off events, where big changes occur in a short time, are not the only thing missing from the IPCC reports. Since the politicians and the public treat the reports as a serious statement about what we must prepare for, they need to be cautioned that the 2007 IPCC reports for the climate science exclude all but the bare minimum consequences.

The IPCC was designed that way and produced a long protracted process where 140 countries have to agree. As the science historian Spencer Weart explained (*New Scientist* 14 April 2007):

The Intergovernmental Panel on Climate Change . . . was created by conservatives [in 1988] to forestall "alarmist" declarations from self-appointed committees of scientists. Governments committed the IPCC to repeated rounds of study and debate, forbidding any announcement except by unanimous consensus. It seemed a sure formula for paralysis.

However, the power of democratic methods, combined with rational argument, overcame all

obstacles. The IPCC has evolved into a robust transnational institution that provides authoritative conclusions of grave significance.

And, I might add, richly deserving of the 2007 Nobel Peace Prize.

The bare-minimum emphasis was augmented by framing the issue as "Are you really sure?" rather than as an evaluation of risk. The climate scientists then allowed climate modeling to become the gold standard and so anything that could not be represented by a reliable number in a known physical process—say, the chance of a catastrophic failure of the West Antarctic Ice Sheet—was simply omitted.

Thus sea level rise in this century was forecast as being in the range of 0.3 m because it focused mostly on such easy-to-model aspects as the thermal expansion of the oceans and a drip-by-drip melting of the ice surface. It left out the possibility of a vast acceleration in the production of icebergs, which raise sea level without even melting. And of course there are many areas where the science is just starting to get estimates, such as evaluating the extra humidity created by irrigation and reservoirs.

The feedbacks included in the models are only beginning to take into account the possibility that their parameters might change, as when the stomata in a leaf narrow down as the CO₂ levels rise. This may reduce the carbon sinks enough to almost double the excess carbon, giving us a 1000 ppm CO₂ (720 ppm excess) at the end of the century whereas IPCC models now say 700 ppm (420 ppm excess) for the business-as-usual emissions scenario.

Finally, most climate scientists are trained to think in terms of certainty, not in terms of risk and its management. They try for understatement. While physicians and senior military officers are trained to think in terms of a window of opportunity that is closing, most of us were not. We must, nonetheless, rise to the occasion.

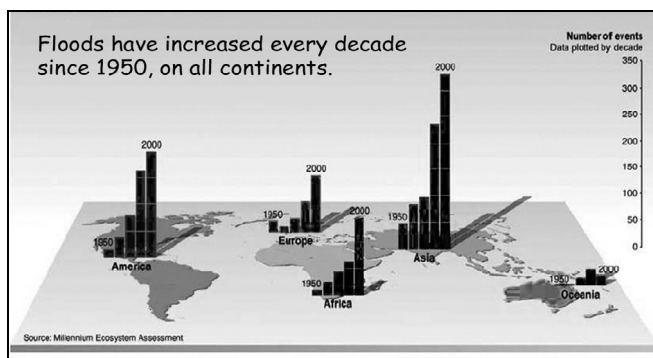
Fifty Years of Climate Change (Already)

Global warming raises land temperatures more than sea surface temperatures (the sea

³ 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.

provides unlimited evaporative cooling). A greater difference between land and sea surface temperatures will increase wind strengths.

If you plant 20 percent more, you expect to get a crop that is 20 percent greater. But some things are “nonlinear” as when a windstorm goes from 50 mph to 60 mph and the insurance claims go up not 20 percent but 500 percent. Guess what will happen to the cost of windstorm insurance? The forecast is for more typhoons and more tornados; many will be stronger as well.



The predictions for rainfall? More in northern Europe, less in southern Europe and North Africa. But even if you could find an in-between area where the 20-year-average rainfall didn't change, the forecast says the *extremes* will widen, with a much higher chance of a ten-year drought and many more episodes of heavy rain that cause landslides and big floods. It is the extremes that do the damage. The same is true elsewhere where the averages are creeping.

With more heating of the tropics, they will expand—and it has already started. The deserts to the south of the tropics are being pushed farther south, creating trouble in a band about 32°S that includes Cape Town and Perth. At about 32°N, dryness is setting in throughout the Mediterranean. In the Americas at about 32°N, southern California and a band from Alabama to Virginia is in drought.

Hot, dry, and windy—all part of the climate forecast—has always been a good recipe for promoting wild fires. Like the decade-by-decade increase in major floods on most continents, there has been a dramatic increase in the number of wild fires from 1950 to 2000.

Threats to the Ocean Food Chain

Life in the oceans has also been in trouble and it's not just the fisheries decline (often blamed on overfishing). 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 algae 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 to 0.6. 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.

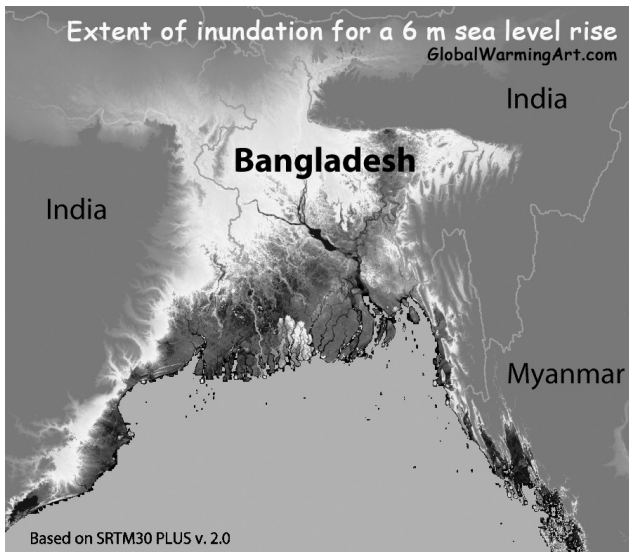
Undermining Ice Sheets

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 would produce there now. The West Antarctic Ice Sheet likely contributed some more water when undermined by the rise in sea level. Undermining by melt water is the problem 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 more quickly and create more icebergs, which instantly raise sea level.

As I mentioned earlier, sea levels may rise more quickly than what the drip-by-drip 2007

IPCC models indicate, which was about 0.3 m this century. 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.

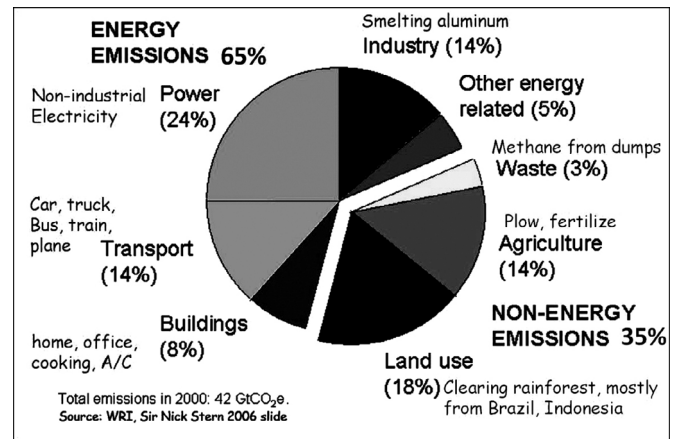


As with refugees from the droughts near the Mediterranean, where will such climate refugees go? What will be the reaction when they cross borders in great numbers? What country will try to take over the resources of a neighbor, pushing its inhabitants out into a third country?

The Four Horsemen of the Apocalypse tend to be featured on such occasions: famine, pestilence, war, and death. The genocides will have a long-lasting legacy: the downsized populations will all hate their neighbors for good reasons.

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) 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 for housing 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, plowing, 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 rotary engine with injections of high-pressure air. I expect this to be a popular choice in the tropics (“That’s cool,” they’ll say) because of the free air cooling for the occupants. India’s largest automaker expects to have 6,000 taxicabs running on compressed air in 2008.

Electricity and its Uses

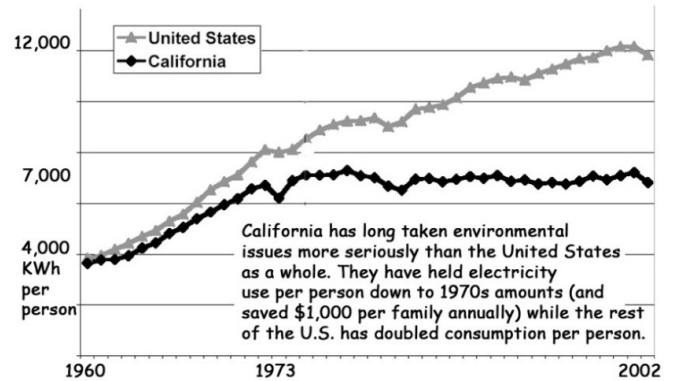
In the U.S., 86 percent of our total energy use comes from fossil fuels. Only 14 percent is clean, mostly from hydro and nuclear.

If we restrict ourselves to electricity generation, then we are 32 percent clean. Thanks to 35 years of expanding nuclear, France’s electricity is 91 percent clean, and in Switzerland, it is 99 percent (half hydro, half nuclear). Next door in Germany, electricity is only 40 percent clean. And 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. 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. Unfortunately, that isn’t fast enough.

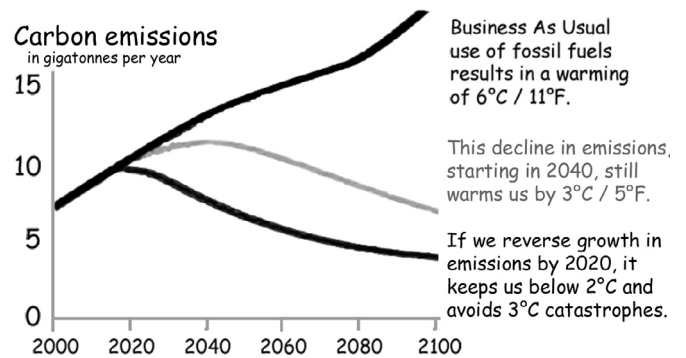
The Window of Opportunity is Rapidly Closing

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.

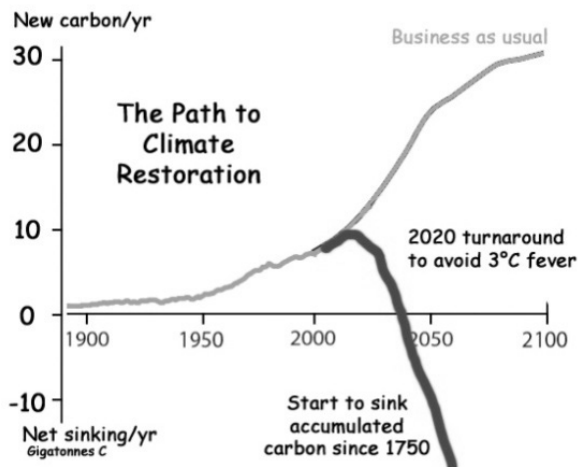
If the world keeps on with Business As Usual expansion of energy use, which is about what both China and the U.S. are doing today, the world will be about 6°C warmer by the end of this century (the interior of continents will warm about twice as much, as will the high latitudes). If the world manages 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. That 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 crossover, where remaining fossil carbon emissions are offset by new carbon sinks, might be called climate stabilization—except for 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 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.”

I have shown the crossover into net sinking as occurring in 2040. The date for true stabilization would be when we have removed all of the fossil carbon that we have dumped into the air since, say, 1939—only because that's when I began personally adding to the problem.

Growing New Carbon Sinks

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

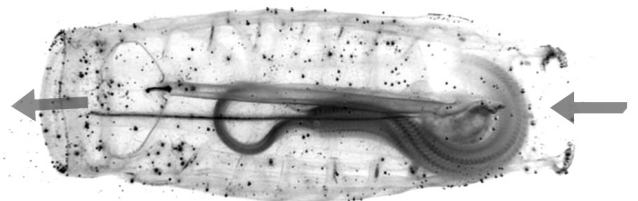
We are more familiar with green leaves but the floating microalgae in the oceans—called phytoplankton and usually seen as unwanted scum on the walls of an aquarium—do more than half of the world's conversion of CO₂ into O₂. Which is fortunate, because of the aforementioned fire hazard from stronger, 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 sink, as those waters are rarely “ventilated” to the atmosphere except on the million year time scale. What do we need to do to sink more carbon?

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.

It is not, however, the primary production that sinks into the ocean depths. 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.



The “Vacuum Cleaner of the Oceans”

A 10 cm *Salpa thompsoni*, via WHOI's Laurence Madin

A second way that the primary production's carbon is sunk is via fecal pellets of larger animals that graze on the plankton. Whales are an extreme example. 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.

Salps are transparent, seldom seen, jelly-like tunicates that filter feed in all oceans. They

multiply into extensive swarms when conditions are right, often sticking to one another side by side to form long ribbons. It would be helpful to understand the ecology and genome of salps well enough to increase their numbers by, for example, prolonging their lifespan.

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.

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. 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 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.

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 utilizing local resources, not likely to include materials for photovoltaic panels, batteries, and fuel cells. Think instead of solar thermal for recharging compressed-air vehicles.

Retrofitting Our Civilization

Preventing the 3° 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.

Our present civilization is like a magnificent cathedral, back before more flying buttresses were added to stabilize the walls. Civilization now needs such a retrofit. It will be a large undertaking, not unlike those that once went into building pyramids and cathedrals. I'm optimistic that the younger generation can create a better civilization during our major makeover—provided that those currently in the leadership can stop this runaway coal train.

Climate change is a challenge to the scientists but I suspect that the political leadership has the harder task, given how difficult it is to make people aware of what must be done and get them moving in time. It's going to be like herding stray cats, and the political leaders who can do it will be remembered as the same kind of geniuses who pulled off the American Revolution in 1776.

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

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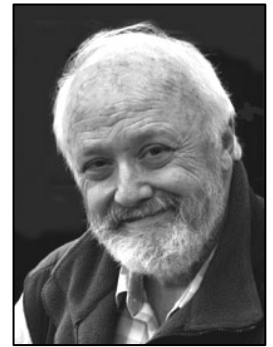
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WILLIAM H. CALVIN, Ph.D.

(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 tool-making 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. His research monograph, *The Cerebral Code: Thinking a Thought in the Mosaics of the Mind* (1996), concerns Darwinian processes in neural circuitry that can operate on the timescale of thought and action to resolve ambiguity and improve the quality of novel courses of action. He also 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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