Source: Alexander Hafemann

Tipping Point

PERSPECTIVE OF A CLIMATOLOGIST

JAMES HANSEN

"Animals are on the run. Plants are migrating too."[1] I wrote those words in 2006 to draw attention to the fact that climate change was already under way. People do not notice climate change because it is masked by day-to-day weather fluctuations, and we reside in comfortable homes. Animals and plants, on the other hand, can survive only within certain climatic conditions, which are now changing. The National Arbor Day Foundation had to redraw its maps for the zones in which tree species can survive, and animals are shifting to new habitats as well. Are these gradual changes in the wild consistent with dramatic scientific assessments of a crystallizing planetary emergency? Unfortunately, yes. Present examples only hint at the scale of the planetary emergency that climate studies reveal with increasing clarity.

Our home planet is dangerously near a tipping point at which human-made

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greenhouse gases reach a level where major climate changes can proceed mostly under their own momentum. Warming will shift climatic zones by intensifying the hydrologic cycle, affecting freshwater availability and human health. We will see repeated coastal tragedies associated with storms and continuously rising sea levels. The implications are profound, and the only resolution is for humans to move to a fundamentally different energy pathway within a decade. Otherwise, it will be too late for one-third of the world's animal and plant species and millions of the most vulnerable members of our own species.

We may be able to preserve the remarkable planet on which civilization developed, but it will not be easy: special interests are resistant to change and have inordinate power in our governments, especially in the United States. Understanding the nature and causes of climate change is essential to crafting solutions to our current crisis.

Tipping Point

Earth is heated by sunlight and, in balance, reaches a temperature such that an amount of heat equal to the absorbed solar energy radiates back to space. Climate forcings are imposed, temporary changes to Earth's energy balance that alter Earth's mean temperature. Forcings include changes in the sun's brightness, volcanic eruptions that discharge sunlight-reflecting particles into the stratosphere, and long-lived human-made greenhouse gases that trap heat.

Forcings are amplified or diminished by other changes within the climate system, known as feedbacks. Fast feedbacks—changes that occur quickly in response to temperature change—amplify the initial temperature change, begetting additional warming. As the planet warms, fast feedbacks include more water vapor, which traps additional heat, and less snow and sea ice, which exposes dark surfaces that absorb more sunlight.

Slower feedbacks also exist. Due to warming, forests and shrubs are moving poleward into tundra regions. Expanding vegetation, darker than tundra, absorbs sunlight and warms the environment. Another slow feedback is increasing wetness (i.e., darkness) of the Greenland and West Antarctica ice sheets in the warm season. Finally, as tundra melts, methane, a powerful greenhouse gas, is bubbling out. Paleoclimatic records confirm that the long-lived greenhouse gases—methane, carbon dioxide, and nitrous oxide—all increase with the warming of oceans and land. These positive feedbacks amplify climate change over decades, centuries, and longer.

The predominance of positive feedbacks explains why Earth's climate has historically undergone large swings: feedbacks work in both directions, amplifying cooling, as well as warming, forcings. In the past, feedbacks have caused Earth to be whipsawed between colder and warmer climates, even in response to weak forcings, such as slight changes in the tilt of Earth's axis.[2]

The second fundamental property of Earth's climate system, partnering with feedbacks, is the great inertia of oceans and ice sheets. Given the oceans' capacity to absorb heat, when a climate forcing (such as increased greenhouse gases) impacts global temperature, even after two or three decades, only about half of the eventual surface warming has occurred. Ice sheets also change slowly, although accumulating evidence shows that they can disintegrate within centuries or perhaps even decades.

The upshot of the combination of inertia and feedbacks is that additional climate change is already "in the pipeline": even if we stop increasing greenhouse gases today, more warming will occur. This is sobering when one considers the present status of Earth's climate. Human civilization developed during the Holocene (the past 12,000 years). It has been warm enough to keep ice sheets off North America and Europe, but cool enough for ice sheets to remain on Greenland and Antarctica. With rapid warming of 0.6°C in the past 30 years, global temperature is at its warmest level in the Holocene.[3]

The warming that has already occurred, the positive feedbacks that have been set in motion, and the additional warming in the pipeline together have brought us to the precipice of a planetary tipping point. We are at the tipping point because the climate state includes large, ready positive feedbacks provided by the Arctic sea ice, the West Antarctic ice sheet, and much of Greenland's ice. Little additional forcing is needed to trigger these feedbacks and magnify global warming. If we go over the edge, we will transition to an environment far outside the range that has been experienced by humanity, and there will be no return within any foreseeable future generation. Casualties would include more than the loss of indigenous ways of life in the Arctic and swamping of coastal cities. An intensified hydrologic cycle will produce both greater floods and greater droughts. In the US, the semiarid states from central Texas through Oklahoma and both Dakotas would become more drought-prone and ill suited for agriculture, people, and current wildlife. Africa would see a great expansion of dry areas, particularly southern Africa. Large populations in Asia and South America would lose their primary dry season freshwater source as glaciers disappear. A major casualty in all this will be wildlife.

Brünnich's guillemot (*Uria lomvia*), an Arctic seabird, has advanced its egg-laying date at its southern boundary, a phenological change due to global warming.

State of the Wild

Climate change is emerging while the wild is stressed by other pressures—habitat loss, overhunting, pollution, and invasive species—and it will magnify these stresses.

Species will respond to warming at differing paces, affecting many others through the web of ecological interactions. Phenological events, which are timed events in the life cycle that are usually tied to seasons, may be disrupted. Examples of phenological events include when leaves and flowers emerge and when animals depart for migration, breed, or hibernate. If species depend on each other during those times—for pollination or food—the pace at which they respond to warmer weather or precipitation changes may cause unraveling, cascading effects within ecosystems.

Animals and plants respond to climate changes by expanding, contracting, or shifting their ranges. Isotherms, lines of a specific average temperature, are moving poleward by approximately thirty-five miles (56 km) per decade, meaning many species ranges may in turn shift at that pace.[4] Some already are: the red fox is moving into Arctic fox territory, and ecologists have observed that 943 species across all taxa and ecosystems have exhibited measurable changes in their phenologies and/or distribution over the past several decades.[5] However, their potential routes and habitat will be limited by geographic or human-made obstacles, and other species' territories.

Continued business-as-usual greenhouse gas emissions threaten many ecosystems, which together form the fabric of life on Earth and provide a wide range of services to humanity. Some species face extinction. The following examples represent a handful. Of particular concern are polar species, because they are being pushed off the planet. In Antarctica, Adelie and emperor penguins are in decline, as shrinking sea ice has reduced the abundance of krill, their food source.[6] Arctic polar bears already contend with melting sea ice, from which they hunt seals in colder months. As sea ice recedes earlier each year, populations of polar bears in Canada have declined by about 20 percent, with the weight of females and the number of surviving cubs decreasing a similar amount. As of this writing, the US Fish and Wildlife Service is still considering protecting polar bears, but only after it was taken to court for failure to act on the mounting evidence that polar bears will suffer greatly due to global warming.[7]

Source: Claire A. Zugmeyer.

The Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) survives on a single mountain in Arizona. "Green islands" on mountains, and the species that live on them, are pushed higher as temperatures rise, and will be pushed off the planet if global warming continues.

Life in many biologically diverse alpine regions is similarly in danger of being pushed off the planet. When a given temperature range moves up a mountain, the area with those climatic conditions becomes smaller and rockier, and the air thinner, resulting in a struggle for survival for some alpine species.

In the Southwest US, the endemic Mount Graham red squirrel survives on a single Arizona mountain, an "island in the sky," an isolated green spot in the desert. The squirrels, protected as an endangered species, had rebounded to a population of over 500, but their numbers have since declined to between 100 and 200 animals.[8] Loss of the red squirrel will alter the forest because its middens are a source of food and habitat for chipmunks, voles, and mice.

A new stress on Graham red squirrels is climatic: increased heat, drought, and fires. Heat-stressed forests are vulnerable to prolonged beetle infestation and catastrophic fires. Rainfall still occurs, but it is erratic and heavy, and dry periods are more intense. The resulting forest fires burn hotter, and the lower reaches of the forest cannot recover.

> Prior major warmings in Earth's history, the most recent occurring 55 million years ago . . . resulted in the extinction of half or more of the species then on the planet.

In the marine world, loggerhead turtles are also suffering. These great creatures return to beaches every two to three years to bury a clutch of eggs. Hatchlings emerge after two months and head precariously to the sea to face a myriad of predators. Years of conservation efforts to protect loggerhead turtles on their largest nesting area in the US, stretching over 20 miles of Florida coastline, seemed to be stabilizing the South Florida subpopulation.[9] Now climate change places a new stress on these turtles. Florida beaches are increasingly lined with sea walls to protect against rising seas and storms. Sandy beaches seaward of the walls are limited and may be lost if the sea level rises substantially.

Some creatures seem more adaptable to climate change. The armadillo, a prehistoric critter that has been around for over 50 million years, is likely to extend its range northward in the US. But the underlying cause of the climatic threat to the Graham red squirrel and other species—from grizzlies, whose springtime food sources may shift, to the isolated snow vole in the mountains of southern Spain—is "business-as-usual" use of fossil fuels. Predicted warming of several degrees Celsius would surely cause mass extinctions. Prior major warmings in Earth's history, the most recent occurring 55 million years ago with the release of large amounts of Arctic methane hydrates,[10] resulted in the extinction of half or more of the species then on the planet.

Might the Graham red squirrel and snow vole be "saved" if we transplant them to higher mountains? They would have to compete for new niches—and there is a tangled web of interactions that has evolved among species and ecosystems. What is the prospect that we could understand, let alone reproduce, these complex interactions that create ecological stability? "Assisted migration" is thus an uncertain prospect.[11] The best chance for all species is a conscious choice by humans to pursue an alternative energy scenario to stabilize the climate.

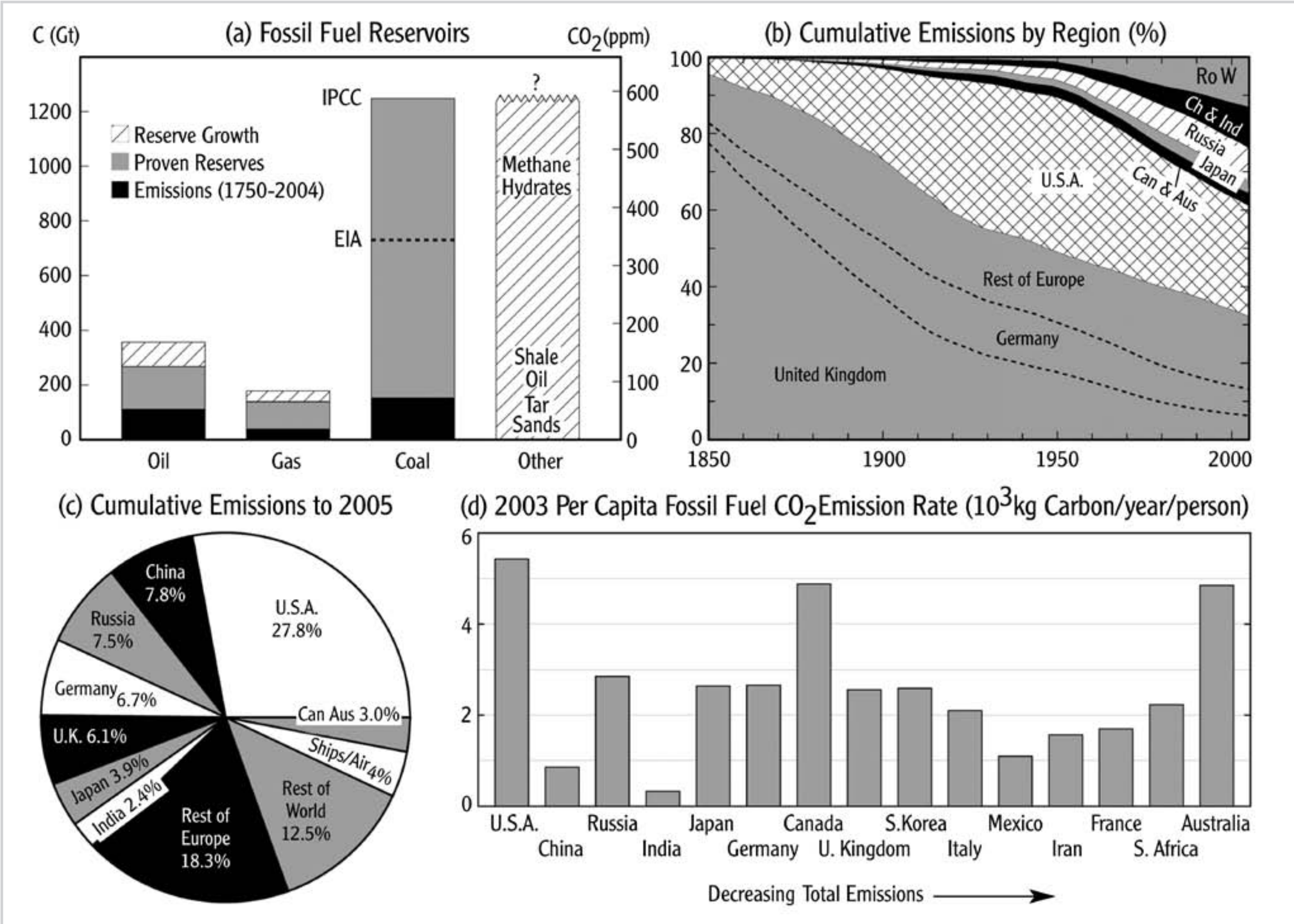
State of the Planet

There is a huge gap between what is understood about global warming—by the scientific community—and what is known about global warming—by those who need to know: the public and policymakers.

The crystallizing science points to an imminent planetary emergency. The dangerous level of carbon dioxide, at which we will set in motion unstoppable changes, is at most 450 parts per million (ppm), but it may be less.[12] Carbon dioxide has already increased from a preindustrial level of 280 ppm to 383 ppm in 2007, and it is now increasing by about 2 ppm per year. We

Source: Turtle Time, Inc.

Loggerhead turtle (*Caretta caretta*) hatchling emerging from egg. Loggerhead decline has been arrested by the protection of nesting areas on Florida beaches and other measures, but these areas will be threatened by rising sea level.



Carbon dioxide contained in fossil fuel reservoirs, (a) the dark areas being the portion already used; (b, c) cumulative fossil fuel carbon dioxide emissions by different countries as a percent of global total; (d) per capita emissions for the 10 largest emitters of fossil fuel carbon dioxide.

must make significant changes within a decade to avoid setting in motion unstoppable climatic change.

We need to address carbon dioxide emissions immediately. Global industrialization, powered first by coal, and later by oil and gas, resulted in fossil fuel pollutants that choked London on smog, set a river on fire in the US, and damaged forests by acid rain. We are solving those pollution problems, but we did not address them until they hit us with full force. That approach, to wait and see and clean up the mess post facto, will not work in the case of carbon dioxide emissions and climate change because of inertial effects, warming already in the pipeline, and tipping points. On the contrary, ignoring emissions would lock in catastrophic climatic change.

Instead, we must resolve to move rapidly to the next phase of the industrial revolution—expanding the benefits of advanced technology to help maintain the atmosphere, and consequently the wonders of the natural world. A review of basic fossil fuel facts reveals why the shift must be made soon. Based on the estimated amount of carbon dioxide locked in each remaining fossil fuel reservoir—including oil, gas, coal, and unconventional fossil fuels (tar sands, tar shale, heavy oil, methane hydrates)[13]—burning readily available oil and gas resources alone will take atmospheric carbon dioxide to levels near 450 ppm. Burning coal and unconventional fossil fuels, which energy companies are now exploring, could take atmospheric carbon dioxide to far greater levels.

To understand the limits on future

In my view, special interests have undue sway with our governments and have effectively promoted minimalist actions and growth in fossil fuels, rather than making the scale of investments necessary.

use of fossil fuels, an awareness of the carbon cycle is critical. In this cycle, the ocean quickly takes up a fraction of carbon dioxide emissions, but uptake slows as carbon dioxide added to the ocean exerts a "back pressure." Further uptake depends upon carbon dioxide mixing into the deep ocean and precipitating out of ocean water via carbonate sediments. This means that about one-third of carbon dioxide emissions remain in the atmosphere after 100 years and one-quarter still remain after 500 years. Indeed, carbon dioxide from the Industrial Revolution still around today implies heavy responsibilities for Europe and the US.

Carbon reservoirs and the ocean's pace of removing carbon dioxide are important boundary conditions in framing solutions to the climate crisis. We can avert planetary transformation—eventual disintegration of ice sheets and massive extinctions—only if the planetary energy balance is restored at an acceptable global temperature. Temperature fluctuates from year to year, but it is increasing by about 0.2°C per decade. Although estimates of permissible warming must be refined as knowledge advances, the upshot of crystallizing science is that the "safe" global temperature level is, at most, about 1°C greater than the year 2000 global temperature.

This 1°C limit on additional global warming implies the aforementioned carbon dioxide ceiling of about 450 ppm.[14] Pinpointing this carbon dioxide ceiling is complicated due to other human-made forcings, especially methane, nitrous oxide, and "black soot." For example, an alternative scenario allows carbon dioxide levels to peak at 475 ppm because it assumes a large reduction of methane.[15] However, human-made sulfate aerosols (reflective particles that have a cooling effect) are likely to decrease, neutralizing these potential reductions in methane. Therefore 450 ppm is a good comprehensive estimate of the maximum allowable carbon dioxide. Indeed, if recent ice loss from Antarctica is a sign, it may be that even 450 ppm is excessive.

Since we could reach 450 ppm within two to three decades, we should be inspired now to change our energy systems. Based on the preceding boundary conditions, the following is a four-point strategy to avoid dangerous climate change.

1. Coal and unconventional fossil fuels must be curtailed and used only with capture and sequestration of the carbon dioxide underground. Existing coal-fired power plants should be phased out over the next few decades.
2. Carbon price and efficiency standards must be implemented. Recognizing the unusual energy concentration and mobility of fossil fuels—with which little else can currently compete—the practical way to transition to a postpetroleum era is to impose a moderate but continually rising carbon price. The price can be via a tax on fossil fuels, a ration-and-trade system that limits impacts on people least able to afford an energy tax, or a combination of methods. This will make fossil fuels pay for environmental damage while stretching remaining oil and gas to accommodate sustainable economic growth. The certainty of a rising price will inspire indus-

tries to innovate and will reduce the incentive to exploit unconventional fossil fuels with high carbon dioxide emissions, such as tar shale.

In addition, we need real efficiency standards, for vehicles, buildings, and lighting. We must remove barriers to energy efficiency, such as the policy of most utility companies to promote energy consumption rather than conservation.

3. We must take steps to draw down atmospheric carbon dioxide. Farming and forestry practices that enhance carbon retention in the soil and biosphere must be supported. Biofuel power plants with carbon sequestration can draw down atmospheric carbon dioxide,[16] putting anthropogenic carbon dioxide back underground. Carbon dioxide can be sequestered beneath ocean sediments[17] and in other safe geologic sites.
4. We must take steps to reduce other, non–carbon dioxide forcings, especially black soot, methane, and ground-level ozone via stricter regulations.

International implementation of these steps requires recognition of responsibilities. Because of the long lifetime of carbon dioxide already emitted, Europe bears a large responsibility. But the responsibility of the US is more than three times that of any other nation, and it will continue to be the largest for at least several decades, even though China will exceed the US in new emissions within a year or two.

Sadly, the requirements to avoid global disasters are not yet widely recognized: Germany intends to replace nuclear power plants with coal. But Europe, the US, and other developed countries should place a moratorium on new coal-fired power plants until carbon capture and sequestration are in place. This cannot wait until similar restrictions are practical in China and India. National responsibilities for climate change and per capita emissions are an order of magnitude greater in the US, Canada, and Australia than in India and China, and define moral obligations.

At the same time, China and developing countries should bulldoze old-technology coal power plants and build new coal power plants with *only* the latest technology. Storms and floods attending climate change will hit developing countries hardest because most megacities near sea level are in those countries. This should provide incentive for China and India to address climate change.

Efficiency of future vehicle power is also vital. California's requirement for 30 percent efficiency improvement has great value. In contrast, a proposed national energy plan for 20 percent ethanol in vehicle fuels, derived in large part from corn, does more harm than good. It will do little to reduce emissions—because producing ethanol currently requires a lot of energy—and it would degrade carbon retention in soils. There are ways that renewable or other carbon dioxide–free energies may eventually power vehicles, but half-measures should not be dictated without sufficient scientific input to balance vested agribusiness interests.

That said, biofuels can play a major part in our energy future. As a native Iowan, I like to imagine that the Midwest will rescue compatriots threatened by rising seas. Native grasses, appropriately cultivated, and perhaps with improved varieties, can draw down atmospheric carbon dioxide. The prairies may contribute, if we get on with solving the climate problem before superdrought hits them. Biofuel investment should proceed with input from scientists and conservationists, because some industry and government biofuel production plans would clear more forest for plantations of oil palm and soy with consequences for wildlife and wildlands.

A Final Picture

Earth's paleoclimatic record tells us that atmospheric greenhouse gases are now near the dangerous level where tipping points become unavoidable.

Source: Philippe Clement/naturepl.com.

Yellow-bellied marmots (*Marmota flaviventris*) advanced their emergence from hibernation by 23 days in the Rocky Mountains, presumably due to global warming.

We can choose a course to reverse greenhouse gas growth and promptly change our energy strategy. A step in the right direction was the April 2007 decision by the US Supreme Court that the Environmental Protection Agency can and should regulate greenhouse gas emissions. However, much more is needed.

In my view, special interests have undue sway with our governments and have effectively promoted minimalist actions and growth in fossil fuels, rather than making the scale of investments necessary.

US government complicity with special interests was clear when, at a practice press conference held by NASA on Arctic sea ice, a member of my group suggested that a reduction in greenhouse gas emissions could stem sea ice loss. His suggestion prompted a government "minder" to proclaim "that's unacceptable," on the grounds that it was a policy statement, when in fact it was scientifically based. While making policy is the right of our elected representatives, scientists had connected the dots of climate research and were prevented from communicating that information. In this case, vested interests posed a threat to our home planet and the fabric of life upon it.

It is worth imagining how our grandchildren will look back on us. The picture that I fear has the polluters, the utilities, and automakers standing in court demanding the right to continue to emit carbon dioxide for the sake of short-term profits. The disturbing part is that we, through our national government, are standing alongside the polluters, officially as a hulking amicus curiae (friend of the court), arguing against limitations on emissions. Is this the picture of our generation that we want to be remembered by?

We live in a democracy, and policies represent our collective will. If we allow the planet to pass tipping points, it will be hard to defend our role. The state of the wild is in our hands, and we can still preserve creation and serve humanity worldwide. A drive for energy efficiency and clean energy sources will produce high-tech jobs. Restoration of clean air will be universally beneficial. Rural life and the planet can benefit from intelligent development of biofuels and renewable energy.

At the front lines, observing the changes in the wild, conservationists serve as a voice for the plants and animals that have already started reacting to climate warming. To conserve as much biodiversity as we can, conservationists must unite with many others to push for a far more radical reduction in carbon dioxide emissions than has hitherto been considered practical. Otherwise, alpine and polar species, coral reefs, and species living in areas that become arid will be lost over the next century.

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