Statement of James E. Hansen

1. Identification, Credentials

I am a United States citizen, director of the NASA Goddard Institute for Space Studies and Adjunct Professor at the Columbia University Earth Institute. I am a member of the United States National Academy of Sciences, have testified before our Senate and House of Representatives on many occasions, have advised our Vice President and Cabinet members on climate change and its relation to energy requirements, and have received numerous awards including the World Wildlife Fund's Duke of Edinburgh Conservation Medal from Prince Philip. I write now, however, as a private citizen, a resident of Kintnersville, Pennsylvania, USA. My full curriculum vitae is available at www.columbia.edu/~jeh1

2. Mechanisms of Climate Change

Dynamics of Weather and Climate: Organized Chaos. Public understanding and recognition of climate change is hindered by the great magnitude of day-to-day weather variability and year-to-year variability of the average weather. Such variability is an inherent property of our atmosphere and ocean. The atmosphere and ocean are fluids in continuous motion, driven by incoming energy from the sun and influenced by the rotation of the Earth and other factors. The fluid motions can be described as organized but chaotic – the fluids are continuously sloshing about. The chaotic component of the motion makes it impossible to predict the temperature in a specific place on a specific day next year or even next month – that depends mainly on what direction the winds will be blowing then, the cloud cover, etc.

On the other hand, if we were to move the Earth closer to the sun, or simply increase the brightness of the sun, we can say with confidence that the Earth would become warmer. It takes time for the Earth to respond to increased sunlight. The climate system has great inertia, mainly due to the ocean, which averages about four kilometers in depth, and thus can absorb a lot of heat. However, we can estimate how long it takes for the climate to respond, and we have tested our understanding of such basic phenomena in many ways. The claim that "we cannot predict next month's weather in London, so how in the world can we predict the effect of human-made greenhouse gases in 50 years!" is a nonsensical statement, failing to recognize the difference between chaotic weather fluctuations and the deterministic response of the Earth to a large change in the planet's energy balance.

Climate Forcings and Feedbacks. A climate forcing is an imposed perturbation of the planet's energy balance, which tends to alter the planet's temperature. Thus a change of solar irradiance is a climate forcing. An imposed change in the amount of long-lived atmospheric greenhouse gases (GHGs), such as carbon dioxide (CO_2), is also a climate forcing.

GHGs absorb infrared (heat) radiation. Adding GHGs to the air makes the atmosphere more opaque at infrared wavelengths where the Earth emits heat radiation. Increased infrared opacity causes emission to space to come from a higher, cooler level in the atmosphere. Thus if GHGs are increased the planet temporarily absorbs more energy from the sun than it radiates as heat. This energy imbalance causes the planet to warm up until energy balance is restored.

Warming begins promptly, but it takes a few decades for the ocean surface temperature to achieve just half of its ultimate ('equilibrium') response, and a few centuries for full response. In the meantime, as the ocean warms, ice sheets begin to melt, becoming darker and smaller, thus further increasing the magnitude of the warming and the time needed to reach full response. This amplifying feedback, well-studied based on the Earth's history, is discussed further below.

Climate forcings are measured in Watts per square meter (W/m^2) averaged over the Earth. If the amount of CO_2 in the air were doubled it would reduce infrared emission to space by 4 W/m^2. Thus doubled CO_2 is a forcing of 4 W/m^2. The Earth absorbs ~ 240 W/m^2 of energy from the sun, so doubled CO_2 is equivalent to increase of solar irradiance by almost 2 percent[1].

Climate feedbacks are changes of the planet's energy balance that occur in response to climate change. The feedbacks can either amplify or diminish the initial climate change. The most powerful feedback is provided by water vapor. The atmosphere holds more water vapor as air becomes warmer, as is readily noticed by comparing summer and winter. Thus water vapor causes a 'positive' or amplifying feedback.

The principal long-lived GHGs, CO_2 and CH_4 (methane), can act as both climate forcings and climate feedbacks. When humans put CO_2 into the air by burning fossil fuels (coal, oil and gas), that is considered a forcing, because it is an imposed change that tends to alter the planet's radiation balance and temperature. However, climate change itself further alters the amount of CO_2 in the air. For example, as the ocean becomes warmer, it releases CO_2 to the air, in part in the same way as the fizz escapes from a warm PepsiCola. Also as the planet warms CH_4 is released by methane hydrates ('frozen methane') in melting permafrost. Both CO_2 and CH_4 provide positive (amplifying) feedbacks for climate change on century time scales.

Observed increases of CO_2 and CH_4 in the air during the past century are primarily a direct consequence of human emissions, but they include smaller feedback contributions. Indeed, one reason to minimize additional global warming is the likelihood that large warming would instigate greater amplifying feedbacks from the extensive deposits of methane hydrates in tundra and on continental shelves.

The fact that GHGs act as both climate forcings, which lead climate change, and climate feedbacks, which lag climate change, has been used by 'contrarians' to sow confusion about global warming. In reality, the leads and lags of GHGs and temperature have occurred just as expected. Indeed, empirical information on GHGs and climate change during Earth's history provides powerful confirmation of our understanding of climate change as well as quantitative evaluation of the level of GHGs that will constitute dangerous interference with nature.

Natural Climate Changes over Millions of Years. A reasonable person, but one not fully cognizant of current knowledge about climate, might ask "Why should we bother to wrestle with human-made climate change? There have been huge climate changes during Earth's history. It is arrogant to think that humans can control climate or that we know enough to say that today's climate is the best one for the planet."

Indeed, Earth has experienced enormous climate variations. The history of how climate responded to changes of planetary boundary conditions provides an invaluable perspective for assessing the role of humans in shaping the planet's destiny. Extraction of information and insight into how climate works requires that we examine glacial-to-interglacial oscillations of recent millennia, but also the larger slower climate changes that occur over millions of years.

The past 65 million years, the Cenozoic Era, provides an example of the large changes over millions of years. Figure 1 shows the global deep ocean temperature through this entire era.

[1] Quantitative evaluation indicates that CO_2 change is (of order at least 10%) more efficacious (in changing planetary surface temperature) than the same amount (in W/m^2) of solar irradiance forcing. Variations in the 'efficacy' of different forcings are expected (http://pubs.giss.nasa.gov/docs/2005/2005_Hansen_etal_2.pdf). Solar forcing is less efficacious than CO_2 forcing because: (1) the CO_2 forcing is almost uniform in latitude, while a change of solar irradiance is greatest at low latitudes – forcings at high latitudes achieve a greater response mainly because of the surface albedo feedback, (2) part of the anomaly in solar radiation is absorbed in the stratosphere, changing the temperature at that level but having little effect on surface temperature.

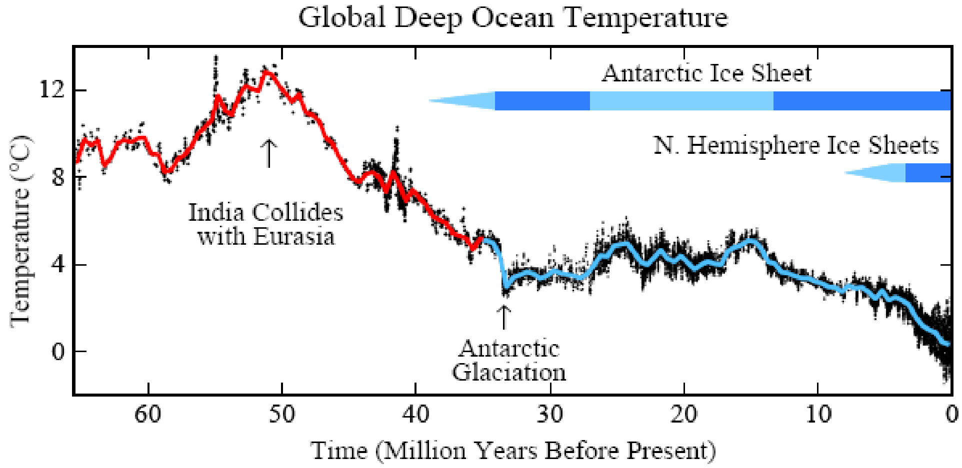

Fig. 1. Global deep ocean temperature, from Hansen et al. (http://arxiv.org/abs/0804.1126). Temperature is derived from the isotopic composition of the shells of microscopic animals that lived in the deep ocean. Blue bars show the times at which ice sheets were present in each hemisphere, dark blue being the times at which the ice sheets were as large as at present or larger[2].

The Earth was much warmer than today in the early Cenozoic. In fact it was so warm that there were no ice sheets on the planet and sea level was about 75 meters higher.

The large climate changes during the Cenozoic Era are especially germane, because tectonically driven changes of atmospheric CO_2 were clearly the dominant global climate forcing for much of that era. Competing climate forcings included the brightness of the sun and the location of the continents, which can change substantially on such long time scales.

Solar luminosity is increasing on long time scales. Our sun is a well-behaved 'main-sequence' star, i.e., it is still 'burning' hydrogen, converting it to helium via nuclear fusion in the solar core. The sun's brightness is increasing at a rate such that solar luminosity today is ~0.4% greater than in the early Cenozoic. Because Earth absorbs ~240 W/m^2 of solar energy, climate forcing due to increased solar irradiance today is about +1 W/m^2 relative to the early Cenozoic.

The lower boundary of the Earth's atmosphere, the area and location of land areas, also changes on long time scales. The size and location of the continents is a climate forcing, because the 'albedo' (literally the 'whiteness' or reflectivity) of the Earth's surface depends on whether the surface is land or water and the latitude of the land area. However, by the early Cenozoic the continents were close to their present latitudes, albeit with the separation of the Americas from Europe-Africa less than at present. Thus the climate forcing due to location of continents has been small, <1 W/m^2 on global average, during the Cenozoic.

Changes of atmospheric CO_2, in contrast to the small climate forcings due to changes of the climate system's upper and lower boundary conditions, caused climate forcing an order of magnitude larger, of the order of 10 W/m^2. Atmospheric CO_2 reached values of 1000-2000 ppm (parts per million; 1000 ppm is 0.1%) in the early Cenozoic, falling to 150-300 ppm in the late Cenozoic (prior to human fossil fuel burning).

Over millions of years the amount of CO_2 in the air can change as a consequence of continental drift, which affects the exchange of carbon between the Earth's crust and surface reservoirs (atmosphere, ocean, soil and biosphere). Specifically, the source of carbon to the surface reservoirs (volcanic eruptions) is not always exactly in balance with the sinks of surface

[2] The temperature curve is based on the average from many ocean sediment cores around the global ocean. For the most recent 34 My, after Antarctica became glaciated, the approximation is made that ocean temperature and ice volume contributed equally to change of isotopic composition.

carbon (weathering of rocks, which deposits carbonate sediments on the ocean floor, and burial of organic material, which may eventually form fossil fuels).

The imbalance of carbon sources and sinks (thus the change of atmospheric CO_2) depends upon plate tectonics (continental drift), because it is the rate of subduction of carbonate-rich ocean crust beneath moving continental plates that determines the rate of volcanic emission of CO_2. Also the rate of weathering (the primary long-term sink of surface carbon) is a function of the rate at which fresh rock is exposed by mountain building associated with plate tectonics.

Specifically, during the period 60 My BP (60 million years before present) to 50 My BP India was plowing north rapidly (20 cm per year) through the Tethys Ocean and in the process subducting carbonate-rich ocean crust, causing atmospheric CO_2 to increase. Global temperature peaked 50 My ago when India crashed into Asia. Available proxy measures of CO_2 indicate that atmospheric CO_2 reached 1000-2000 ppm at that time. The Earth was at least 12°C warmer than today, there were no ice sheets on the planet, and sea level was about 75 meters higher.

With the collision of India and Asia the subduction source for CO_2 emissions declined, but the weathering sink increased as the Himalayas and Tibetan Plateau were pushed up. Thus the past 50 My have generally been a period of declining atmospheric CO_2 and a cooling planet.

An important point to note is the rate of these natural processes. The typical imbalance between tectonic sources and sinks of atmospheric CO_2 is about one ten-thousandths of a ppm of atmospheric CO_2 per year. In one million years this would be a CO_2 change of 100 ppm, which would cause large climate change. This natural rate of change should be compared with the present human-made increase of atmospheric CO_2, which is about 2 ppm per year.

So, yes, it is clear that natural climate changes are huge over long time scales, encompassing even an ice free planet. But now the human-made rate of change of atmospheric CO_2 is ten thousand times larger than the natural rate that drove the huge climate changes. Humans are now in charge of atmospheric CO_2 amount and global climate, for better or worse.

The single most pertinent number emerging from Cenozoic climate studies is the level of atmospheric CO_2 at which ice sheets began to form as the planet cooled during the past 50 million years. Our research suggests that this tipping point was at about 450 ppm of CO_2 (http://arxiv.org/abs/0804.1126 and http://arxiv.org/abs/0804.1135). The history of the Earth's climate shows that global ice cover is reversible, although climate inertia slows the response. If humanity is so foolish as to burn all fossil fuels, thus more than doubling atmospheric CO_2 from its pre-industrial level of 280 ppm, we will have set the planet on an inexorable course to an ice-free state, with all the disasters that such a course must hold for man and beast.

Natural Climate Changes over Millennia. The large climate changes discussed above, occurring over millions of years, are usually slow, because they involve transfer of carbon between the Earth's crust and the surface reservoirs (atmosphere, ocean, soils, and biosphere). But graphs of global temperature (Fig. 1) also show, superposed on these large climate swings, more rapid and regular oscillations of temperature, the familiar glacial-interglacial oscillations that occur over tens and hundreds of thousands of years.

The large glacial-interglacial climate swings are synchronous with and instigated by small changes of the Earth's orbit[3]. The orbital changes alter the seasonal and geographical distribution of sunlight on Earth. The effect of insolation variations is magnified by two strong feedback mechanisms. First, seasonal insolation changes can cause melting or buildup of high

[3] Changes of the Earth's orbit are the eccentricity of the orbit, the day of year at which the Earth is closest to the sun, and the tilt of the spin axis relative to the plane of the orbit. These orbital elements fluctuate due to gravitational tugs of Jupiter, Saturn and Venus as they alternately move closer or farther from the Earth. The orbital perturbations have negligible effect on the amount of solar energy falling on the Earth averaged over the year and planet.

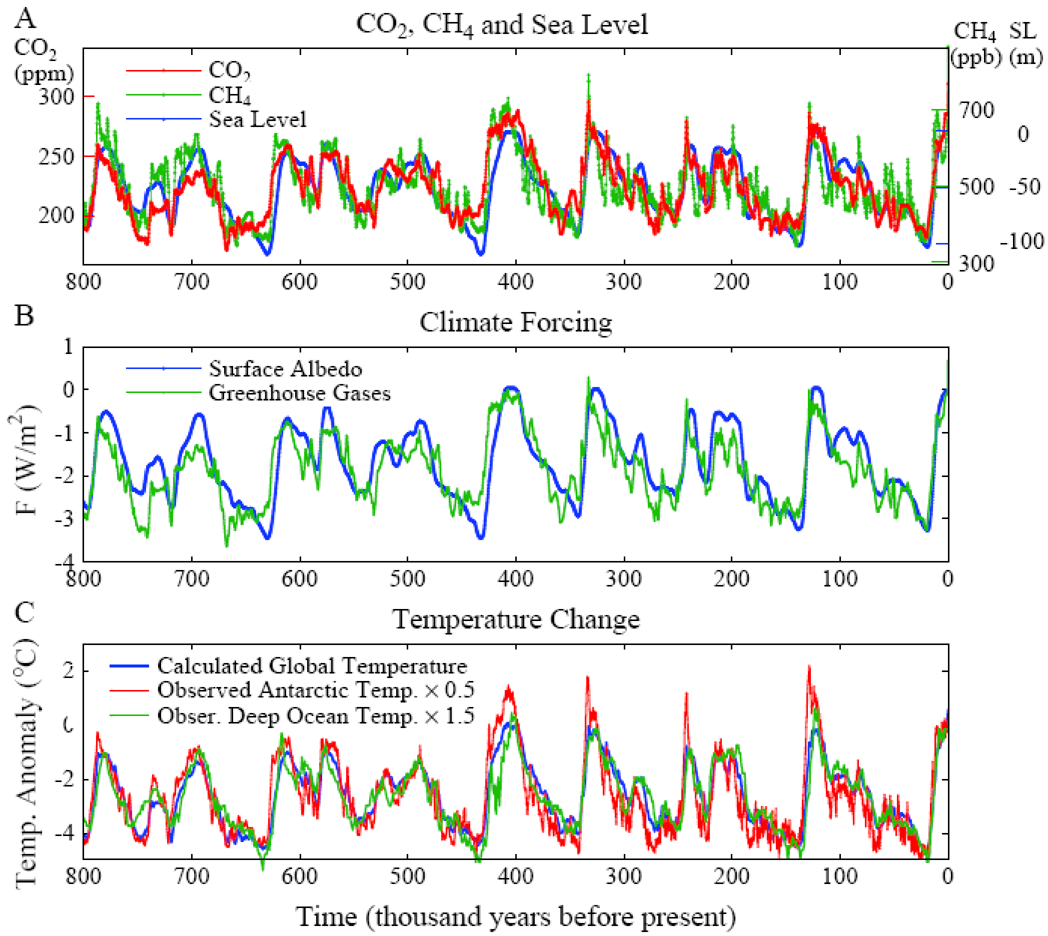

***Figure 2.** (A) CO_2, CH_4 and sea level for the past 800 ky, (B) climate forcings due to changes of GHGs and ice sheet area, the latter inferred from sea level change, (C) calculated global temperature change for a climate sensitivity 3/4°C per W/m^2 compared with temperatures obtained from an Antarctic ice core and global ocean sediment cores. Polar surface temperature change is about twice global temperature change as a result of feedbacks that amplify high latitude change; deep ocean temperature change is less than the surface temperature change, because Pleistocene deep ocean temperature change is limited by the freezing point (*http://arxiv.org/abs/0804.1126*).*

latitude ice sheets, bringing into play the powerful ice-albedo feedback. Second, when the planet warms (cools) the ocean, soil and biosphere release (absorb) CO_2, CH_4 and N_2O, these GHGs providing another powerful amplifying feedback[4]. Glacial-interglacial changes of ice sheet size and CO_2 amount are large (of order 100 meters of sea level and 100 ppm of CO_2) and practically coincident (Fig. 2A).

The direct forcing due to orbit changes is negligible, the annual mean perturbation of the Earth's energy balance never exceeding 0.2 W/m^2 averaged over the planet. But the ice-albedo and GHG feedbacks each cause (approximately equal) perturbations of several W/m^2 (Fig. 2B). Together these two feedbacks fully account for the global temperature swings from glacial to interglacial conditions (Fig. 2C), with a climate sensitivity of 3/4°C per W/m^2 of forcing, or 3°C

[4] CO_2 provides most of the GHG feedback. CO_2 is released by the ocean as the climate warms because of the temperature dependence of CO_2 solubility and increased ocean mixing in a warmer climate, which flushes out deep ocean CO_2 and alters ocean biological productivity.

for doubled CO_2 forcing. This empirical climate sensitivity confirms the climate sensitivity estimated by most climate models[5].

Close examination of glacial-interglacial data reveals that temperature change usually leads the GHG change. This is as expected, because the GHG change is a feedback to the temperature change. The average lag is a few hundred years, the time required for CO_2, which is the dominant GHG feedback, to be flushed from surface reservoirs, mainly from the ocean[4].

Despite longstanding knowledge that GHGs changes are a feedback amplifying glacial-interglacial global temperature change, and thus GHG changes necessarily lag temperature change, global warming 'contrarians' point to this lag as proof that GHGs are not an important cause of climate change! This deception, whether a product of ineptitude or slyness, serves to confuse the public or at least make it appear that there is an argument among theorists.

Natural climate changes on millennial time scales are instigated by Earth orbital changes, but the mechanisms causing planetary energy imbalance and global temperature change are the ice-albedo and GHG feedbacks. Both mechanisms are now under control of humans: GHGs have increased far above levels that existed during the past few million years and ice sheets are disintegrating in both hemispheres. Humans will determine future climate change.

But shouldn't Earth now, or at some point, be headed into the next ice age? No. Another ice age will not occur, unless humans go extinct. Orbital conditions now are, indeed, conducive (albeit weakly[6]) to initiation of ice sheet growth in the Northern Hemisphere But only a small amount of human-made GHGs are needed to overwhelm any natural tendency toward cooling. The long lifetime of human-made CO_2 perturbations assures that no human generation that we can imagine will need to be concerned about global cooling. Even after fossil fuel use ceases and its effect is drained from the system an ice age could be averted by chlorofluorocarbons (CFCs) produced in a single CFC factory. It is a trivial task for humanity to avert an ice age.

3. Implications of Climate Change

Potential consequences of global warming, should fossil fuel use continue unchecked, are enormous. I begin with two impacts that are irreversible on time scales of interest to humanity: (1) sea level rise due to ice sheet disintegration, and (2) extermination of species. Some regional impacts of fossil fuel burning, discussed below, are happening faster, are more obvious today, and also strongly affect life, limb, property, and quality of living.

Yet sea level rise and species extinction illuminate best the generational inequity of present policies and actions of governments, utilities, and the fossil fuel industry. This inequity is the source of consternation for young people and others concerned about the future of young people and the unborn, and the future of the Earth and life on the planet.

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[5] This empirical sensitivity, as opposed to the model result, has the advantage that it surely includes all physical mechanisms, because it is based on real world data. Note that this empirical sensitivity does not include the slow amplifying feedbacks that occur on times scales of centuries as ice sheets melt, forests migrate, and GHGs are released by the soil or ocean, because the surface albedo and GHG amounts were treated as specified boundary conditions in evaluating the empirical climate sensitivity.

[6] The eccentricity of the Earth's orbit is unusually small now, i.e., the orbit is very close to being circular. Thus orbital perturbations of seasonal insolation are smaller than in cases when the orbit is more elliptical. Because of the small ellipticity of the orbit it is possible that, absent humans, the current interglacial period may have lasted 30-40 ky, analogous to the interglacial period about 400 ky ago, rather than having the more common duration of 10-20 ky. That question is now rhetorical and moot, as humans have taken over the carbon cycle and determination of atmospheric GHG amounts.

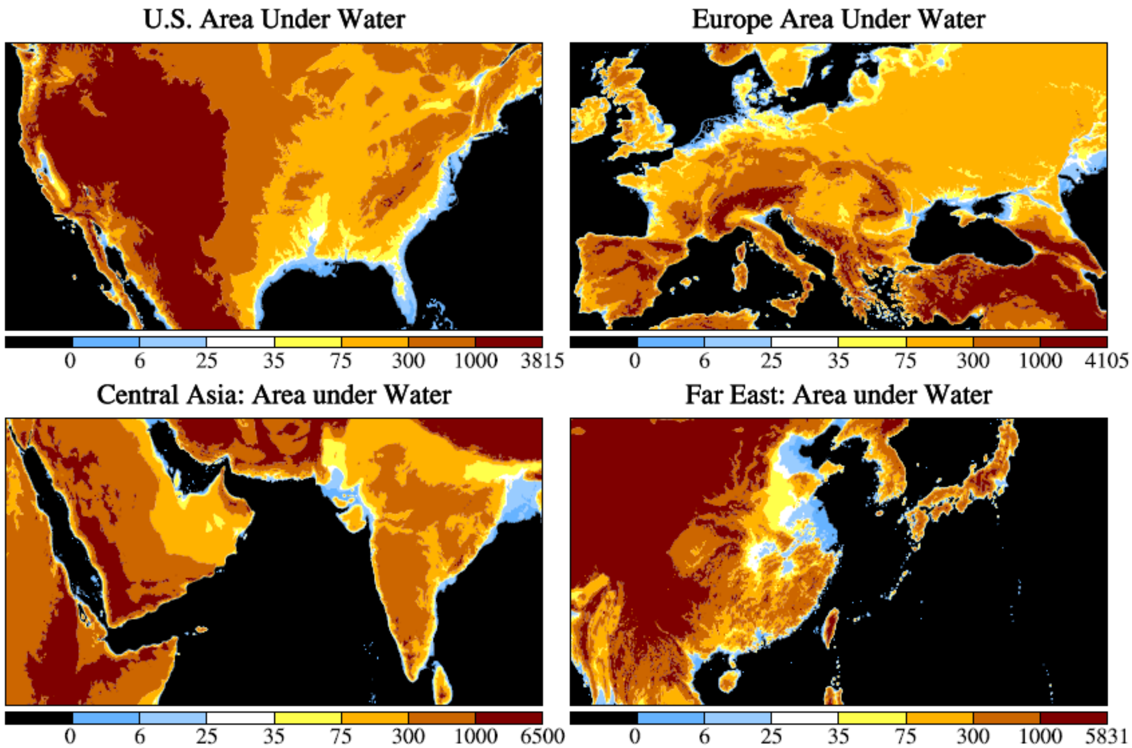

Fig. 3. Dark and light blue areas show regions that will be inundated with sea level rise of 6 and 25 meters, respectively. The last time sea level was 25 meters higher was in the Pliocene, about 3 million years ago, when the deep ocean was about 1°C warmer than today (Fig. 1); global surface temperature exceeded deep ocean temperature change in this period, but by less than a factor of two.
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Tipping points. Present rates of sea level rise and species extinction are already rapid compared to rates of change in recent millennia. However, there is special danger posed by the 'non-linear' nature of some physical and biological processes, a danger that is described as 'tipping points' of the climate and life systems[7].

A tipping point in the climate system occurs when there are large, ready positive (amplifying) feedbacks, such as Arctic sea ice, West Antarctic and Greenland ice sheets, and frozen methane hydrates. These feedbacks can partner with the inertia of the oceans and ice sheets to create a situation in which the warming 'in the pipeline', due to human-made GHGs already in the air, can carry climate to large rapid changes without any additional forcing.

Biological systems, too, have tipping points, because the interdependency of species means that habitat disturbance and species loss can reach a point that causes ecosystem collapse[8].

The Earth's history reveals numerous cases in which sea level rose rapidly, at a rate of several meters per century, and also cases of mass extinctions in which more than half the species on the planet went extinct in conjunction with global warming of several degrees.

Sea level rise. Sea level is now increasing at a rate of about 3 cm per decade or about one-third of a meter per century. This rate of sea level rise is about twice as large as the rate in the twentieth century[9]. At this rate, sea level changes will lead to salt water intrusion into fresh water aquifers and increase the damage of storm surges.

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[7] "Tipping Point: Perspective of a Climatologist": http://pubs.giss.nasa.gov/docs/2008/2008_Hansen_1.pdf

[8] C. Parmesan, "Ecological and evolutionary response to recent climate change", Annual Review of Ecology and Evolution of Systems 37, 637-669, 2006.

[9] IPCC 2007, Climate Change 2007: The Physical Basis, http://www.ipcc.ch/SPM2feb07.pdf

The main concern about sea level, however, is the likelihood that continued global warming could lead to ice sheet disintegration and much greater sea level increase. The prior interglacial period was warmer than the current one by at most 1°C on global average, yet sea level was as much as 4-6 meters higher. The last time that global surface temperature was as much as 2°C warmer than now was in the Pliocene, 3-5 million years ago, when sea level was about 25 meters higher. If all fossil fuels were burned, more than doubling the amount of CO_2 in the air, the eventual global warming would be expected to exceed 3°C, possibly leading to an ice-free planet, as in the early Cenozoic (Fig. 1), with sea level about 75 meters higher.

The greatest scientific uncertainty concerns the time required for the ice sheets to respond to global warming. Estimates for 21st century sea level rise (about a quarter to half a meter) by the Intergovernmental Panel on Climate Change (IPCC)[9] excluded any possible contribution from disintegration of the Antarctic and Greenland ice sheets, perhaps leaving the impression that they believed there would be little ice sheet response in a century.

Regardless of their intention, accumulating evidence from both the Earth's history and current events occurring on the ice sheets and in the oceans bordering the ice sheets, provide strong evidence that continued global warming is likely to initiate substantial ice sheet response. This evidence is a cause of great concern among glaciologists, even though there are several reasons for 'scientific reticence'[10] to sound an alarm about a matter that is inherently difficult to predict because of its non-linear character.

What we can say is that when ice sheets have gone unstable in the past sea level rise at rates as large as 3-5 meters per century have occurred, indeed, such rates have occurred in conjunction with climate forcings much smaller than the expected human-made business-as-usual climate forcing of the 21st century. We can also say that there is evidence of accelerating activity on and around the ice sheets. Marine ice shelves that buttress the West Antarctic ice sheet are melting at rates of several meters per year. Summer surface melt on the ice sheets is increasing in area and moving higher up the ice sheets. Both Greenland and West Antarctica now have net annual mass losses exceeding 100 cubic kilometers of ice.

My opinion[11] is that IPCC business-as-usual climate forcing scenarios are so huge and unprecedented that sea level rise of at least 1-2 meters within century, with more unavoidably in the pipeline, would be practically a dead certainty. A measure of the range of scientific assessments can be garnered from the response elicited from one of the principal IPCC authors to my statement "…if these IPCC projected rates of sea level rise (excluding ice sheet contributions) are taken as predictions of actual sea level rise, as they have been by the public, they suggest that the ice sheets can miraculously survive a business-as-usual climate forcing assault for a period of the order of a millennium or longer"[10] – his response being strong denial that they believed the ice sheets could survive a millennium.

So estimates of the time required for a large ice sheet response seem to range only from a century or less to a few centuries. Thus the issue is only whether disastrous consequences will be visited upon our children or their descendants. Once ice sheet disintegration is underway it can proceed under its own momentum and is unstoppable – we cannot tie a rope around or build a wall around a disintegrating behemoth ice sheet.

Species extermination. Plants and animals are accustomed to climate fluctuations. What has changed recently is the steady global warming, at a rate of about 0.2°C per decade, which has brought global temperature close to the peak level of the current interglacial period. This trend is shifting climate zones and isotherms (lines of a given average temperature) poleward, at a rate of

[10] 'Scientific reticence and sea level rise' http://pubs.giss.nasa.gov/docs/2007/2007_Hansen.pdf
[11] 'A slippery slope: how much warming is dangerous?' http://pubs.giss.nasa.gov/docs/2005/2005_Hansen.pdf

about 50-60 kilometers per decade, and upward. Given that the strong warming trend is only about 30 years, so far, it has not yet had a big impact on species extinction. However, business-as-usual scenarios would have this warming rate continuing through the century and even increasing in its rate.

Such a business-as-usual scenario surely would lead to a great increase of extinctions and the possibility of ecosystem collapse. The Earth's history shows that past global warmings of several degrees caused mass extinctions of more than half the species on the planet, even though the natural climate changes were generally slower than the human-made change. Of course new species came into being over paleoclimate time scales, but mass extinctions now would leave our descendants with a much more desolate planet for as many generations as we can imagine.

Regional climate impacts. Global warming causes intensification of both extremes of the hydrologic cycle. On the one hand, stronger heat waves, droughts and forest fires, are associated with the generally higher temperature. On the other hand, because a warmer atmosphere holds more water vapor, there will be heavier rains and greater floods. Stronger storms fueled by latent heat, including thunderstorms, tropical storms and tornados will be experienced in a warmer world.

Theory and models indicate that subtropical regions expand poleward with global warming[12]. Data reveal a 4-degree latitudinal shift already[13], larger than model predictions, yielding increased aridity in southern United States[14], the Mediterranean region, Australia and parts of Africa. Impacts of this climate shift[15] are already substantial on the world's poor as well as in developed countries.

Mountain glaciers are in near-global retreat[16]. After a flush of fresh water, glacier loss foretells long summers and autumns of frequently dry rivers, including rivers originating in the Himalayas, Andes and Rocky Mountains that now supply water to hundreds of millions of people. If business-as-usual fossil fuel use continues, most mountain glaciers of the world will be lost within 50 years.

Regional climate change and shifting climate zones will be a general problem, because civilization and life on the planet are adapted to climate zones of the Holocene. If business-as-usual continues, with most fossil fuels burned this century, the rate of climate change is likely to be unprecedented with consequences that are difficult to forecast in detail.

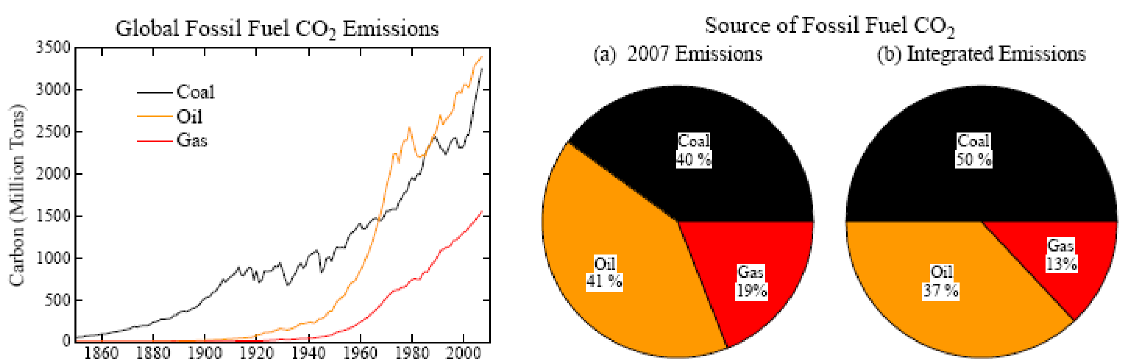

Fig. 4. Left: fossil fuel emissions versus time. Right: proportions of fossil fuel emissions in 2007 (a) and integrated emissions (b). Climate change is proportional to integrated emissions[18].

[12] I.M. Held & B.J. Soden, J. Climate, 19, 5686-5699, 2006.
[13] D.J. Seidel & W.J. Randel, J. Geophys. Res., 111, D21101, 2006.
[14] T.P. Barnett et al., Science, 319, 1080-1083, 2008; B.G. Levi, Phys. Today, April 16-18, 2008.
[15] IPCC Climate Impacts volume, ed. M. Parry et al., Cambridge Univ. Press, New York, 2007.
[16] T.P. Barnett et al., Nature, 438, 303-309, 2005.

4. Coal's Contribution to Climate Change

Coal was almost the only source of fossil fuel CO_2 emissions until about 1920 (Fig. 4, left side). CO_2 emissions from oil accelerated rapidly after WW II, passing coal emissions in the early 1960s. Coal use accelerated in the past several years, and by 2007 global CO_2 emissions from coal (40%) had almost caught those of oil (41%), with gas at 19%. Given evidence that the world is approaching peak oil production, and the fact that recoverable resources of coal are much larger than those for oil, coal will surely become the dominant source of future atmospheric CO_2, unless a conscious decision is made to limit emissions from coal.

Coal, specifically prompt phase-out of coal emissions, is the one critical element in solution of the global warming problem, in preservation of a planet resembling the one on which civilization developed. That fact is clear, if one accepts two facts that are difficult to contradict: (1) coal has the largest reservoir of carbon among the fossil fuels, as summarized by the bar graph in Fig. 5, and (2) the readily available reserves of oil and gas will be exploited and most of their CO_2, which mainly comes out of tailpipes, will not be captured. It does not matter much how rapidly the oil and gas are used because of the long lifetime of emitted CO_2, much of which remains in the air more than 1000 years.

Purple areas in Fig. 5a are emissions to date; reserves (blue) are uncertain. Expert opinion suggests that we are now close to "peak oil" production, which implies that about half of the oil has been used already. Thus reserve estimates labeled IPCC probably are more realistic than those of EIA, the latter including large estimates for undiscovered reserves. There are uncertainties in coal reserves as well, but it is known that there is sufficient coal to get CO_2 to 500 ppm and higher, well into the dangerous level of atmospheric CO_2.

5. Urgency of Taking Action

It will be necessary to return atmospheric CO_2 to 350 ppm or lower on a time scale of decades, not centuries, if we hope to avoid destabilization of the ice sheets, minimize species extinctions, and halt and reverse the many regional climate trends discussed above[17]. There is just barely still time to accomplish that, but it requires an immediate moratorium on new coal-fired power plants that do not capture and sequester CO_2 and a phase out of existing coal plants over the next 20 years.

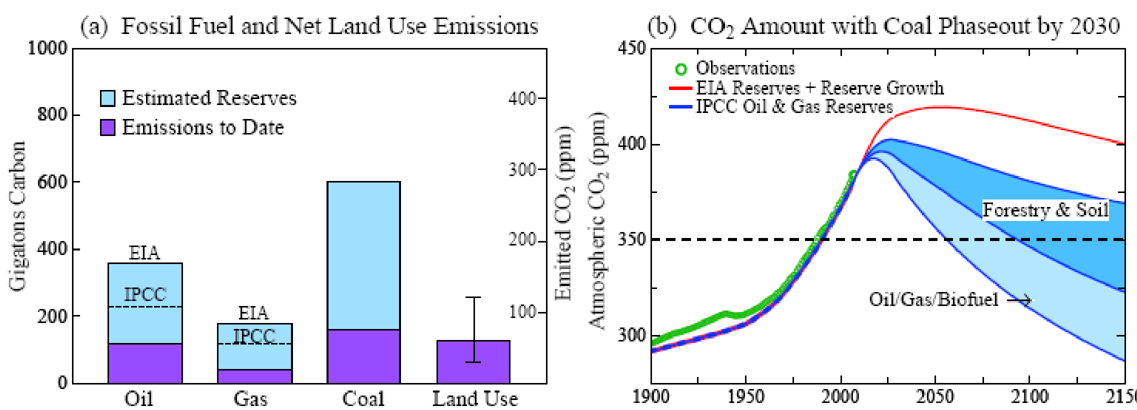

Fig. 5. (a) carbon sources, and (b) CO_2 scenarios if coal emissions are phased out linearly over 2010-2030 period; return below 350 ppm can be hastened via reforestation and carbon sequestration in soil, and further via capture of CO_2 at gas-fired power plants.

[17] 'Target atmospheric CO_2: Where should humanity aim?' http://arxiv.org/abs/0804.1126

Fig. 5b shows that if coal CO_2 emissions were phased out over 2010-2030, atmospheric CO_2 would peak at 400-425 ppm. In that case it would just be feasible to get atmospheric CO_2 back beneath 350 ppm via the carbon uptake potential of improved forestry and agricultural practices, which could draw down atmospheric CO_2 by as much as about 50 ppm. If it turns out that actual oil and gas reserves are toward the higher end of the estimated range, then it may be necessary to capture and sequester CO_2 at some of the gas-fired power plants, or to burn appropriate biofuels (not food crops) at power plants that capture and sequester CO_2.

Such actions to correct modest overshoot of the safe atmospheric CO_2 level are feasible, under the assumption that the maximum CO_2 level is kept not too far from 400 ppm. That result is possible only if there is a prompt stoppage of construction of coal-fired power plants, which is the reason for the urgency of a moratorium on new coal-fired power plants.

If, instead, coal use continues to expand (as it is now, see below), CO_2 will be headed to the 500-600 ppm range, or higher if unconventional fossil fuels such as tar shale are developed. In this "Damn the consequences! Full speed ahead with all fossil fuels!" case (a.k.a., business-as-usual), we will hand our children a planet that has entered a long chaotic transient period with climate changes out of their control, as the planet heads inexorably toward an ice-free state.

A critical fact is the long lifetime of fossil fuel CO_2 emissions. Half of a fossil fuel CO_2 pulse disappears within 20-30 years, mostly into the ocean. However, much of the CO_2, about one-fifth, is still in the air after 1000 years. Because of this long CO_2 lifetime, we cannot solve the climate problem by slowing down emissions by 20% or 50% or even 80%. It does not matter much whether the CO_2 is emitted this year, next year, or several years from now. Therefore, instead of a percent reduction in the rate of emissions, we must identify a portion of the fossil fuels that will be left in the ground, or captured upon emission and put back into the ground.

To summarize: the issue is <u>how</u> to keep maximum CO_2 close to 400 ppm, thus retaining the possibility to get CO_2 back below 350 ppm in a reasonable time, thus preserving life and a planet similar to the one on which civilization developed. Readily available oil (the big pools, being tapped already) surely will be used, and this oil-CO_2 will end up in the air, because it is used in vehicles, where CO_2 cannot be captured. To argue otherwise requires asserting that Russia, Middle East countries, and others will be willing to leave their oil in the ground.

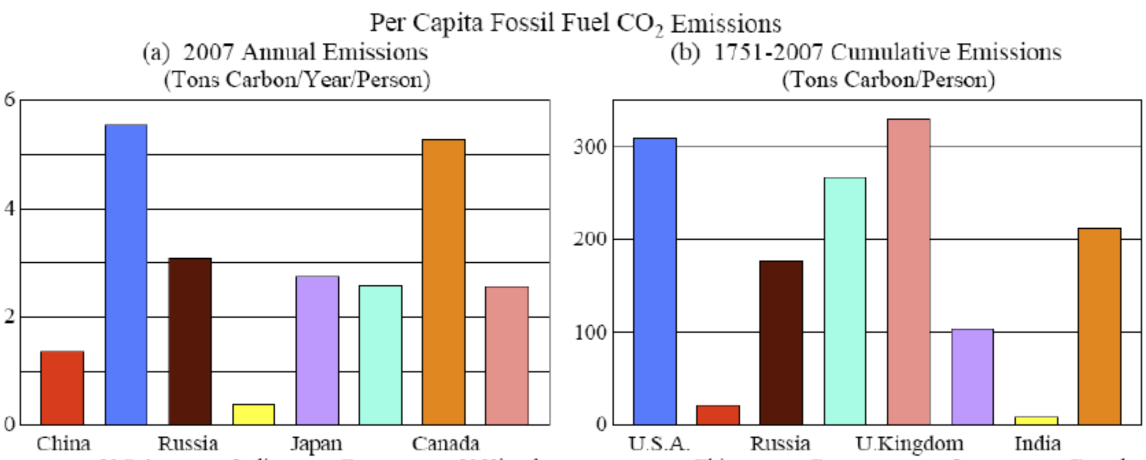

Fig. 6. Per capita (today's population) fossil fuel CO_2 emissions by the eight countries with largest 2007 emissions (a) and largest 1751-2007 cumulative emissions (b), with the countries ranked in order of emissions. Data sources: CDIAC (Carbon Dioxide Information Analysis Center) and BP (British Petroleum).

6. Implications

Why is this power plant in the UK so important, when China and India are building a large number of power plants? The answer is provided by data on the history of fossil fuel emissions, and logical inferences therefrom.

Per capita emissions in the UK today are about twice those of China (Fig. 6a). However, the climate change induced by these emissions is proportional to cumulative emissions[18]. As Fig. 6b shows, the UK, US and Germany, in that order, are the most responsible for today's climate change on a per capita basis. Their responsibility, on a per capita basis, exceeds that of China by more than a factor of 10, and that of India by more than a factor of 25.

Yet China and India must be part of the solution of global warming. The black segments in the bar graphs of Fig. 7 are the portions of today's energy consumption derived from coal in the 20 countries with greatest energy use. And developing countries are not only large consumers of coal, their coal use is the most rapidly growing.

Developed countries, being responsible for most greenhouse gases in the atmosphere today, have a clear obligation to find a course for themselves that has the potential of bringing developing countries into a solution. But what is the course being followed by developed countries? It is illustrated in Fig. 8, which shows fossil fuel CO_2 emissions versus time by fuel type for Japan, the U.S., Germany and the UK.

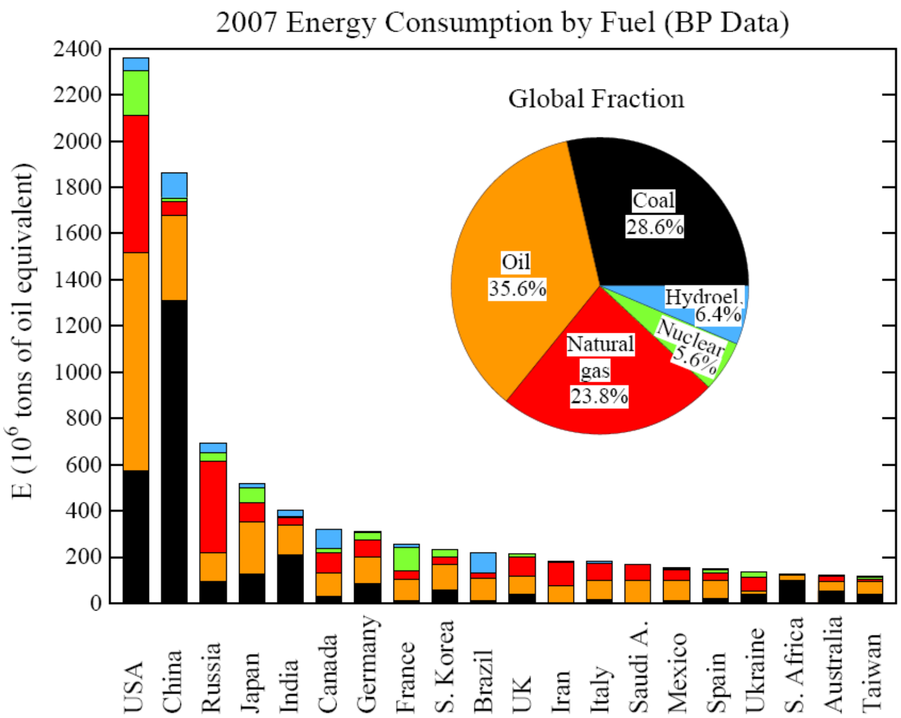

Fig. 7. Energy consumption by fuel type in 2007, based on BP data.

[18] "Dangerous human-made interference with climate": http://pubs.giss.nasa.gov/docs/2007/2007_Hansen_etal_1.pdf

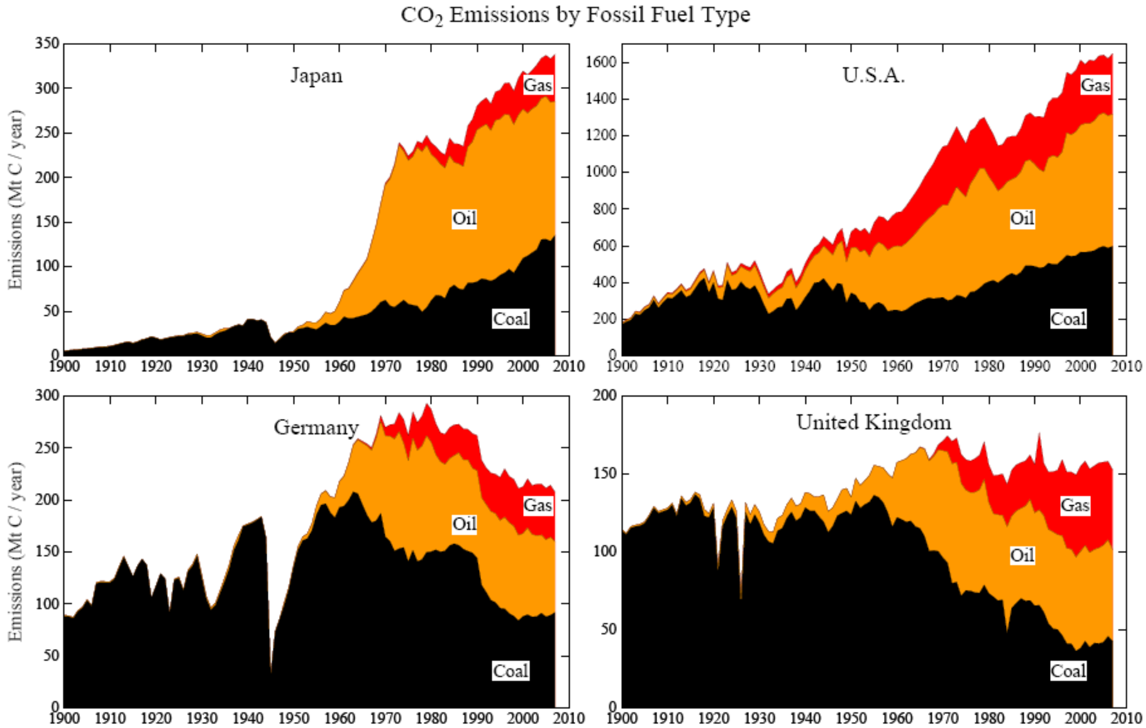

Figure 8. CO_2 emissions by fossil fuel type in four countries. Note the different scales, emissions from the United States being several times larger than those of the other countries.

In the second half of the 20th century Germany and the UK achieved large reductions in coal use, in part by closing inefficient industrial uses in East Germany and with the help of North Sea gas. But in the 21st century coal use is accelerating in all four countries. This is a prescription for planetary disaster. Can there be any hope of convincing China and India to turn away from coal if coal use is increasing in the West?

7. Summary Facts

These summary facts were known by the UK government, by the utility EON, by the fossil fuel industry, and by the defendants at the time of their actions in 2007:

(1) **<u>Tipping Points</u>:** the climate system is dangerously close to tipping points that could have disastrous consequences for young people, life and property, and general well-being on the planet that will be inherited from today's elders.

(2) **<u>Coal's Dominant Role</u>:** Coal is the fossil fuel most responsible for excess CO_2 in the air today, and coal reserves contain much more potential CO_2 than do oil or gas. Coal is the fossil fuel that is most susceptible to either (a) having the CO_2 captured and sequestered if coal is used in power plants, or (b) leaving the coal in the ground, instead emphasizing use of cleaner fuels and energy efficiency.

(3) **<u>Recognized Responsibilities</u>:** The UK is one of the nations most responsible for human-made CO_2 in the air today, indeed, on a per capita basis it is the most responsible of all nations that are major emitters of CO_2. This fact is recognized by developing countries, making it implausible that they would consider altering their plans for coal use if the UK plans to continue to rely on coal-fired power.

(4) **<u>Recognized Impacts of Climate Change</u>:** The UK government, EON, and the fossil fuel industry were aware of the likely impacts of continuation of coal emissions, specifically impacts on future sea level, extinctions of animal and plant species, and regional climate effects, i.e., they were all aware that their actions would contribute to these adverse impacts, leaving a more impoverished planet for today's young people and the unborn.

(5) **<u>Greenwash</u>:** Governments, utilities, and the fossil fuel industry have presented public faces acknowledging the importance of climate change and claiming that they are taking appropriate actions. Yet the facts, as shown in this document, contradict their claims. Construction of new coal-fired power plants makes it unrealistic to hope for the prompt phase-out of coal emissions and thus makes it practically impossible to avert climate disasters for today's young people and future generations.

Recognition of these basic facts by the defendants, realization that the facts were also known by the government, utility, and fossil fuel industry, and realization that the actions needed to protect life and property of the present and future generations were not being taken undoubtedly played a role in the decision of the defendants to act as they did.