STATE OF IOWA
DEPARTMENT OF COMMERCE
BEFORE THE IOWA UTILITIES BOARD

IN RE:	)	
	)	Docket No. HLP-2014-0001
DAKOTA ACCESS LLC	)	

DIRECT TESTIMONY OF

JAMES E. HANSEN

ON BEHALF OF

SIERRA CLUB IOWA CHAPTER

OCTOBER 12, 2015

EXHIBIT SIERRA CLUB-JH-1

STATE OF IOWA
DEPARTMENT OF COMMERCE
BEFORE THE IOWA UTILITIES BOARD

IN RE:	)	
	)	Docket No. HLP-2014-0001
DAKOTA ACCESS LLC	)	

DIRECT TESTIMONY OF DR. JAMES E. HANSEN

Q. Please state your name and present employment.

A. My name is James Hansen. I am an adjunct professor in the Columbia University Earth Institute and Director of the Program on Climate Science, Awareness and Solutions at the Columbia University Earth Institute in New York City.

Q. What was your prior employment?

A. I began working at the Goddard Institute for Space Studies of the National Aeronautics and Space Administration in 1967. From 1981 to 2013 I was the Director of the Goddard Institute.

Q. What is your educational background?

A. I received a B.A. degree in Physics and Mathematics in 1963, an M.S. degree in Astronomy in 1965, and a Ph.D. in Physics in 1967, all from the University of Iowa.

Q. Is Exhibit Sierra Club-JH-2 your curriculum vitae?

A. Yes

Q. During your employment at the Goddard Institute did you study what has come to be known as climate change?

A. Yes.

Q. How did you first become aware of climate change?

A. In my early research I used telescopic observations of Venus to extract detailed information on the physical properties of the cloud and haze particles that veil Venus. Since the mid-1970s, I have focused on studies and computer simulations of Earth's climate, for the purpose of understanding the human impact on global climate. Some of that work informed my testimony on climate change to Congress in the 1980s, which testimony aimed at raising broad awareness of the global warming issue.

Among that work was *Climate impact of increasing atmospheric carbon dioxide,* a paper that colleagues and I published in the journal *Science* in 1981. In it, we observed that global temperature had risen approximately 0.2°C between the middle 1960s and 1980, an increase consistent with calculations of the effect of the measured increase in atmospheric carbon dioxide. We anticipated that anthropogenic carbon dioxide warming should emerge from the noise level of natural climate variability by the end of the century, and that there would be a high probability of warming in the 1980s. We concluded, as well, that potential effects on climate in the 21st century would include the creation of drought-prone regions in North America and central Asia as part of a shifting of climatic zones, erosion of the West Antarctic ice sheet with a consequent worldwide rise in sea level, and opening of the fabled Northwest Passage.

Q. What have you done recently to draw attention to this matter?

A. In recent years I have attempted to draw attention to the danger of passing climate tipping points -- irreversible climate impacts that could yield a different planet from the one on which civilization developed. I think it is critical for regulators and policy makers at all levels to dispute the contention of fossil fuel interests that all fossil fuels must be burned, with their combustion products discharged into the atmosphere.

I have also outlined steps that are needed to restore our planet's energy balance and stabilize climate, with a cleaner atmosphere, productive ocean system, and retention of intact ecosystems on which our children and future generations alike will depend.

Q. You have spoken of the climate crisis. Can you describe the nature of that crisis?

A. I can. It is now clear, as the relevant scientific community has established for some time, that high CO_2 emissions from fossil fuel burning have already disrupted Earth's climate system and that, unless we fundamentally alter business as usual, the build up of atmospheric CO_2 will impose profound and mounting risks of ecological, economic and social collapse.

The fundamental metric is Earth's present and growing energy imbalance. There remains a real, but time-limited, opportunity to commence a phase-down of CO_2 and other GHG (greenhouse gas) emissions so as to restore energy balance, and stabilize the climate system. But increased exploitation of fossil fuel reserves, including from the Bakken formation, cuts sharply in the wrong direction. It will flood the market and reduce the impetus for development of and reliance upon non-carbon sources of energy.

In conjunction with a number of colleagues I have written recently about the urgent need to reduce the atmospheric CO_2 concentration to no more than 350ppm, so as to restore Earth's energy balance. I have also written about the real risk to our nation and coastal cities throughout the world of multi-meter sea level rise that will occur if we fail to phase out emissions and restore energy balance over the coming decades.

Q. Have you provided the Utilities Board with your recent study establishing the need to sharply reduce fossil fuel emissions?

A. I have. Exhibit Sierra Club-JH-3 is a copy of Hansen, et. al, *Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, PLOS One (Dec. 3, 2013).[1] That study, published in conjunction with 17 colleagues, established that continued fossil fuel burning up to even 2°C above the preindustrial level[2] likely would cause large climate change with disastrous and irreversible consequences.

Accordingly, actions to rapidly phase out CO_2 emissions, along with efforts to increase the sequestration of carbon, are urgently required so as to reduce the atmospheric CO_2 concentration to no more than 350ppm and restore Earth's energy balance.

I hereby incorporate by reference its analyses and conclusions into my testimony.

Q. Have you provided the Board with your recent study warning of multi-meter sea-level rise?

---

[1] Available, as well, at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0081648.

[2] We are already 0.9°C above the preindustrial temperature. Indeed, in 2015 global temperature is reaching a level ~1°C above the preindustrial level, but the high 2015 level is partly a temporary effect of a strong El Nino, a natural oscillation of tropical Pacific Ocean temperature.

A. I have. Exhibit Sierra Club-JH-4 is a copy of Hansen, et. al., *Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous*. It was published in July of this year, in conjunction with 16 colleagues.[3]

In it we conclude that, if CO_2 emissions are allowed such that energy is continuously pumped at a high rate into the ocean, then multi-meter sea level rise will become practically unavoidable, with consequences that may threaten the very fabric of civilization.

I hereby incorporate by reference its analyses and conclusions into my testimony.

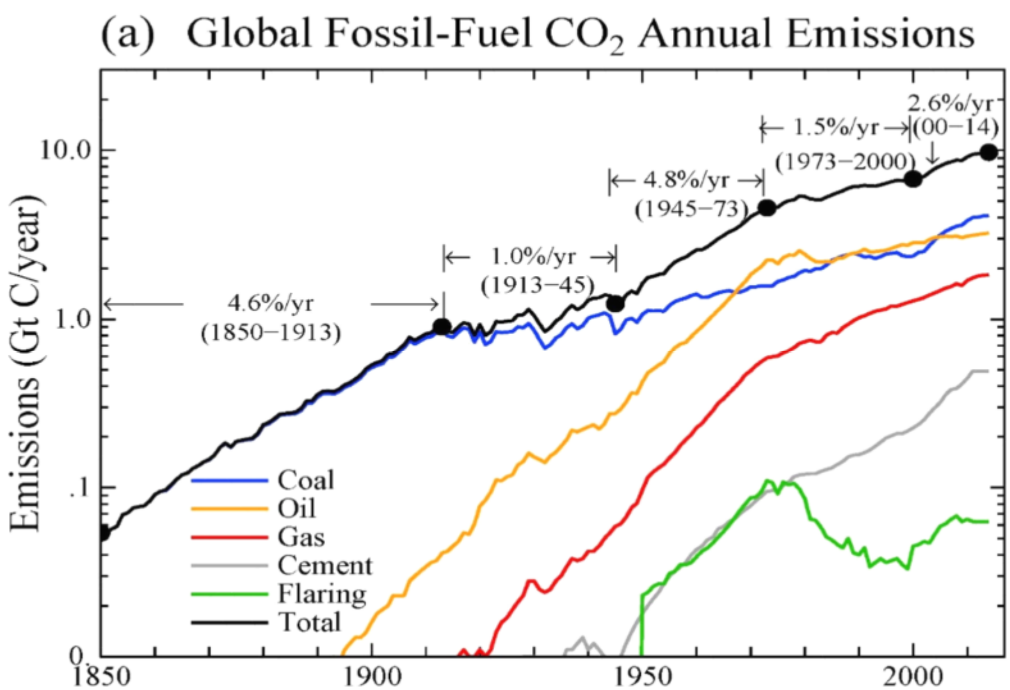
Q. Could you explain what you mean by your observation that Earth is increasingly out of “energy balance”?

A. Yes. I can do this with the assistance of several graphics.

In Chart 1, I show global fossil fuel CO_2 emissions on an annual basis from the burning of coal, oil, and natural gas, and from cement production and flaring, along with the total emissions from these major sources. Although it is more than twenty years since 170 nations agreed to limit

[3] Also available at: http://www.atmos-chem-phys-discuss.net/15/20059/2015/acpd-15-20059-2015.pdf

fossil fuel emissions in order to avoid dangerous human-made climate change, the stark reality – as illustrated here – is that global emissions have accelerated. Specifically, the growth rate of fossil fuel emissions increased from 1.5%/year during 1973–2000 to 2.6%/year in 2000–2014 (Chart 1(a)), due in the main to increased utilization of coal, oil, gas and cement (Chart 1(b)).



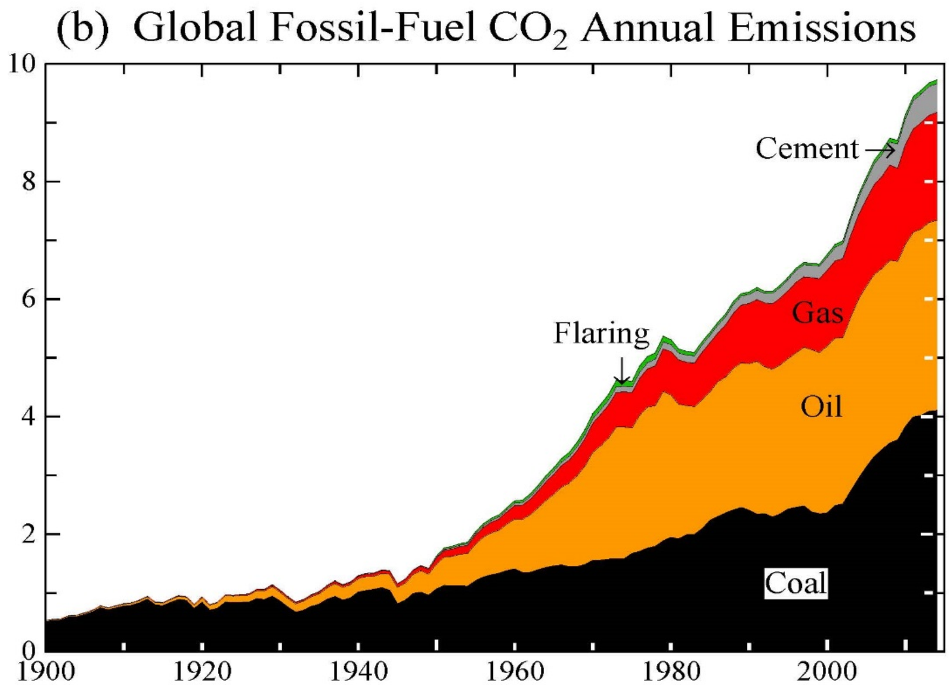


Chart 1: CO_2 Annual Emissions From Fossil Fuel Use And Cement Manufacture
Source: *Dangerous Climate Change* (Exhibit_Sierra Club-JH-3 to this Declaration, at Fig. 1), updated through 2014 from http://www.columbia.edu/~mhs119/CO2Emissions/.

Our increased emissions are reflected, at least in part, in the rising concentration of atmospheric CO_2, as is illustrated in Chart 2,[4] based on readings taken at the Mauna Loa, Hawaii, observatory. The CO_2, atmospheric level is now approximately 400 ppm, over 40 percent more than the preindustrial level.

[4] *From* http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_growth

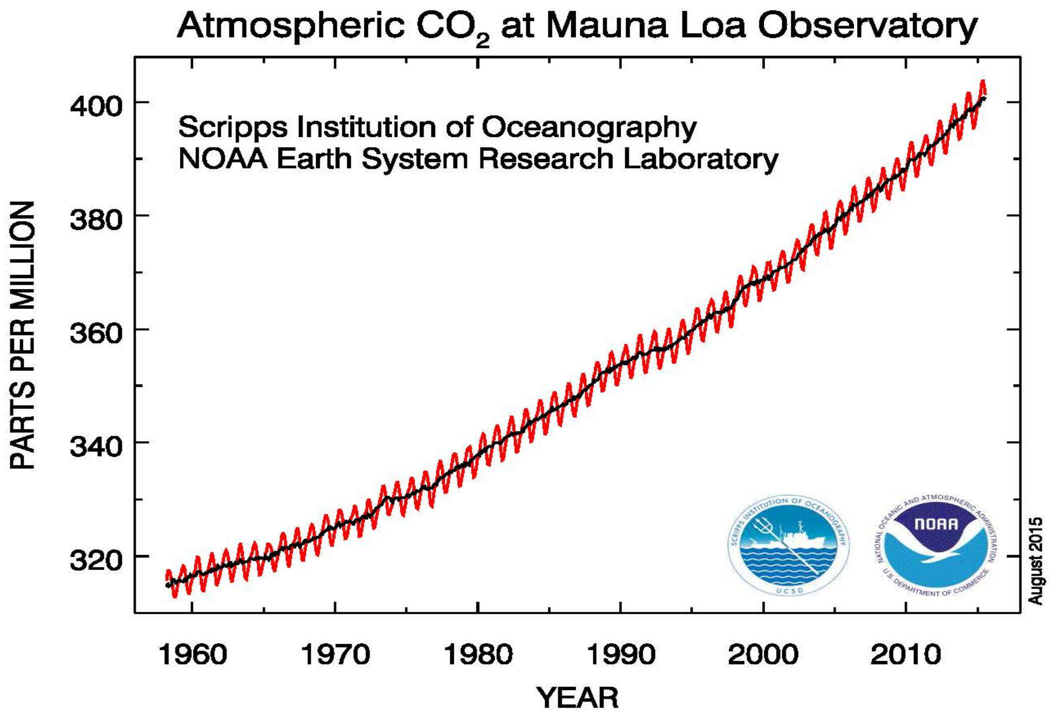


Chart 2: From NOAA's Earth System Research Laboratory at http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full.

Moreover, the *increase* in the atmospheric CO_2 concentration is itself speeding up, as is illustrated in Chart 3.[5] The annual mean rate of CO_2 growth more than doubled from 0.85ppm in the 1960-70 period to 2.0ppm in 2000-2010.

[5] *Id.*

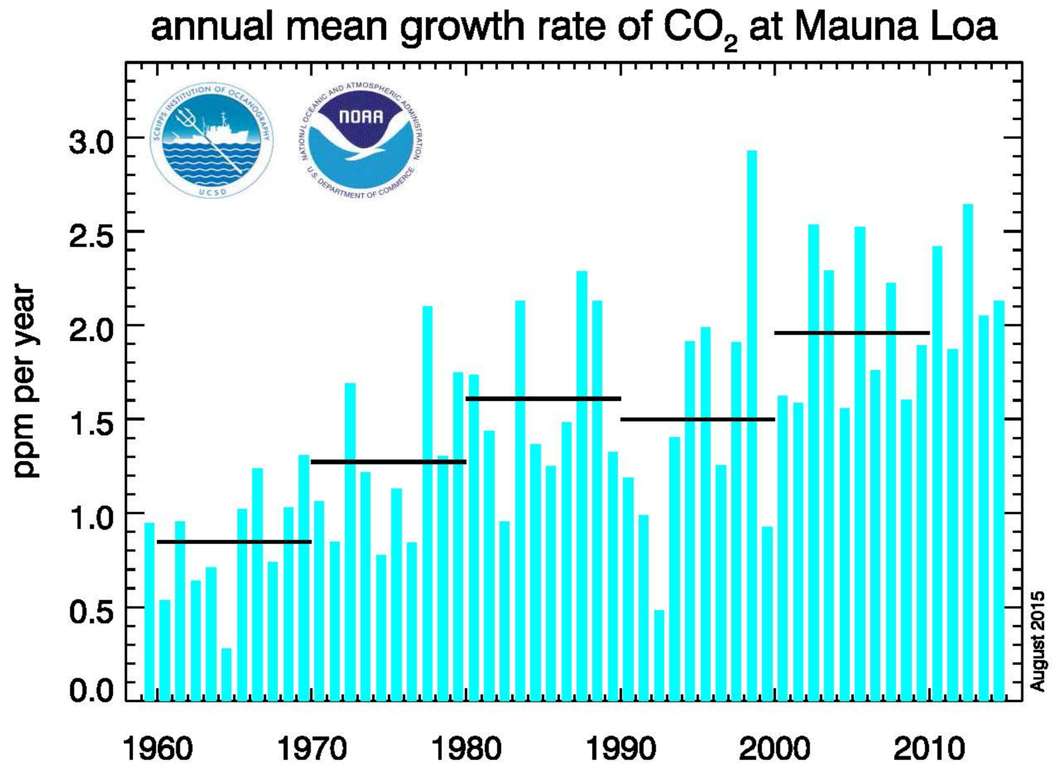


Chart 3: From Noaa's Earth System Research Laboratory at http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_growth.

This increased concentration of CO_2 and other GHGs in the atmosphere operates to reduce Earth's heat radiation to space, thus causing an energy imbalance – less energy going out than coming in. This imbalance causes Earth to heat-up until it again radiates as much energy to space as it absorbs from the sun.

In point of fact, warming of Earth caused by the increasingly thick CO_2 "blanket" persisted even during the recent five-year solar minimum from 2005-2010. Had changes in insolation been the dominant forcing, the planet would have had a negative energy balance in that period, when solar irradiance was at its lowest level in the period of accurate data, i.e., since the 1970s. Instead, even though much of the greenhouse gas forcing had been expended in causing observed 0.9°C global warming to date, the residual positive forcing from CO_2 emissions overwhelmed the reduced solar energy flux. This illustrates, unequivocally, that it is human activity, and not the sun, that is the dominant driver of recent climate change.

Q. Who, or what, is responsible for these emissions and the resulting build up of atmospheric carbon?

A. In a sense, responsibility is shared by all adults who, over the last 35 years, have been both capable of understanding even the summaries of the relevant scientific reports and yet did nothing effective to stem the tide.

In terms of emissions by nation of origin I will note, first, that it is true, as we can illustrate with the aid of Chart 4 (a) (left side), that in recent years, CO_2 emissions from China have exceeded those from the U.S.

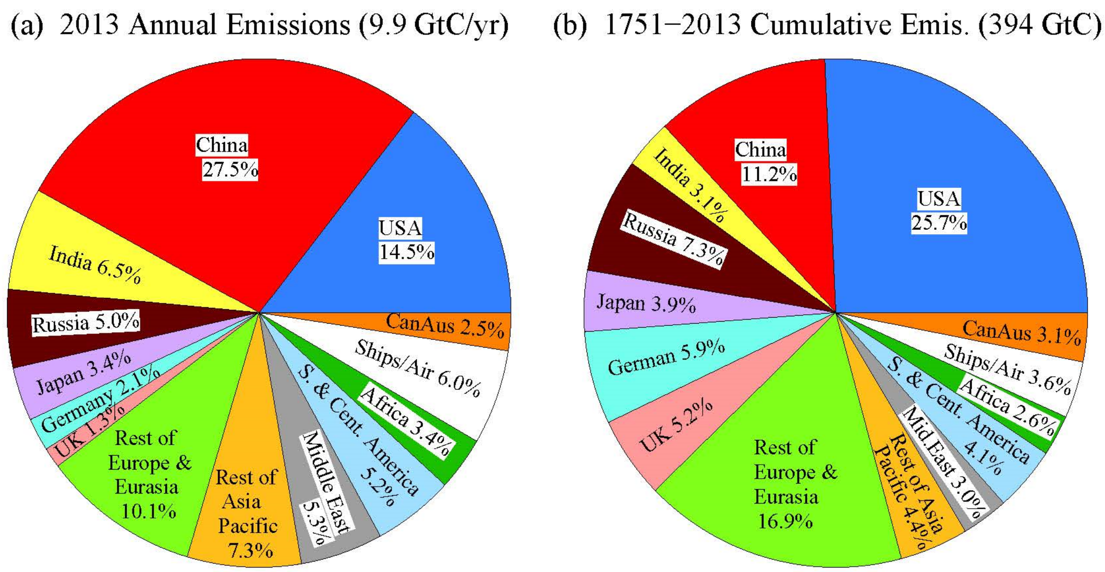


Chart 4: Fossil Fuel CO_2 Emissions
Source: *Dangerous Climate Change* (Exhibit Sierra Club-JH-3 to this Declaration at Fig. 11) updated through 2013 at http://www.columbia.edu/~mhs119/CO2Emissions/Emis_moreFigs/.

However, in light of the long residence time of CO_2 following its injection into the atmosphere, it is a nation's sum total of its emissions that is the more proper measure of its responsibility for already-realized and latent climate change. *See* Chart 4 (b) (right side). That chart illustrates that the United States is more responsible than any other for the present dangerously-highly atmospheric CO_2 concentration.

Q. What do you mean by "long residence time" of CO_2?

A. A pulse of CO_2 injected into the air decays by half in about 25 years, as CO_2 is taken up by the ocean, biosphere and soil, but nearly one-fifth remains in the atmosphere after 500 years. This is illustrated in Chart 5, below. Indeed, that estimate is likely optimistic, in light of the well-known nonlinearity in ocean chemistry and saturation of carbon sinks, implying that the airborne fraction probably will remain larger for a century and more. It requires hundreds of millennia for the chemical weathering of rocks to eventually deposit all of this initial CO_2 pulse on the ocean floor as carbonate sediments.

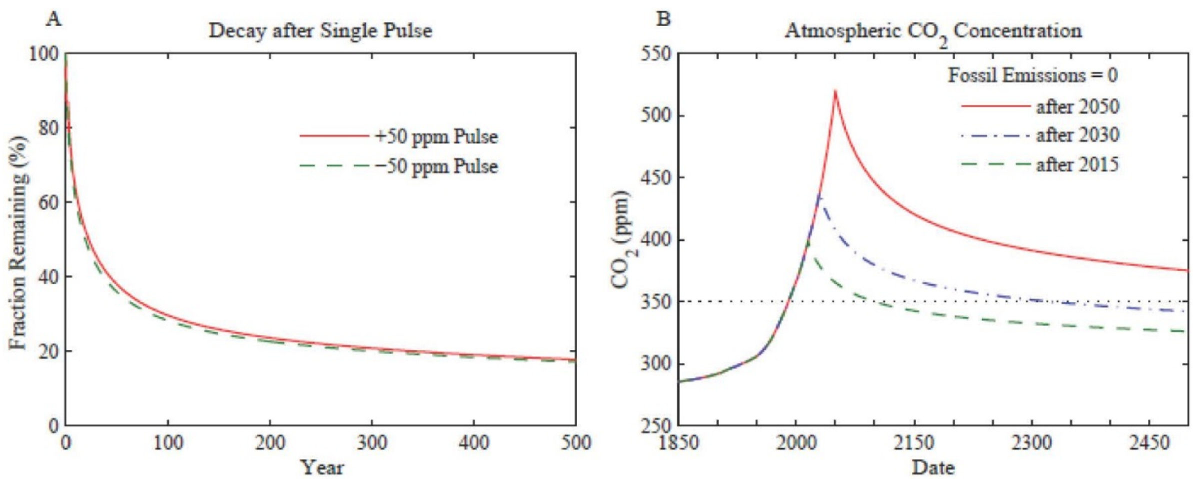


Chart 5: Decay Of Atmospheric Co_2 Perturbations
Source: *Dangerous Climate Change* (Exhibit Sierra Club-JH-3 to this Declaration at Fig. 4). (A) Instantaneous injection or extraction of CO_2 with initial conditions at equilibrium. (B) Fossil fuel emissions terminate at the end of 2015, 2030, or 2050 and land use emissions terminate after 2015 in all three cases, i.e., thereafter there is no net deforestation.

The critical point here is that carbon from fossil fuel burning remains in the climate system, with much of it in the atmosphere, and thus continues to affect the climate system for many millennia.

Q. What does that imply with respect to responsibility for the climate crisis?

A. It is in part for this reason – the atmospheric persistence of CO_2 – that our national contribution to the problem is so large. Moreover, we can observe that, as compared with that of other major CO_2-emitting nations, our national contribution to the global climate crisis is not only largest in absolute amount (Chart 4b), it dwarfs the contributions of the most populous nations on a per capita basis. I have illustrated this below in Chart 6.

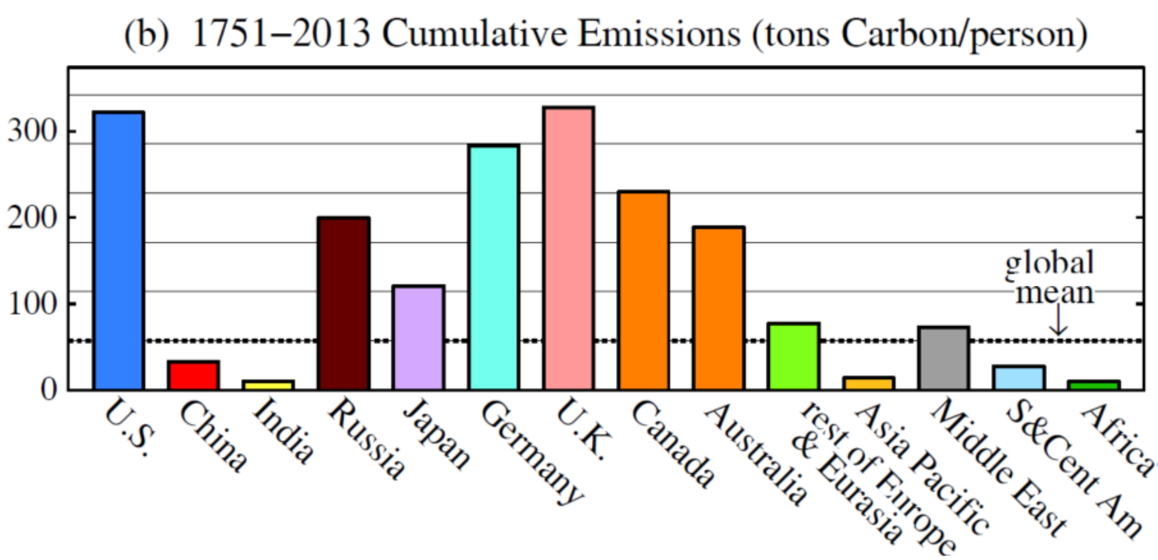


Chart 6: Cumulative Per Capita Carbon Dioxide Emissions
Source: www.columbia.edu/~mhs119/YoungPeople/.

Q. What has all this meant in terms of global warming to date, and what does it mean for our future?

A. In sum, the increasing atmospheric CO_2 has warmed the planet. Chart 7, below, shows the upward march of recent average global surface temperature.

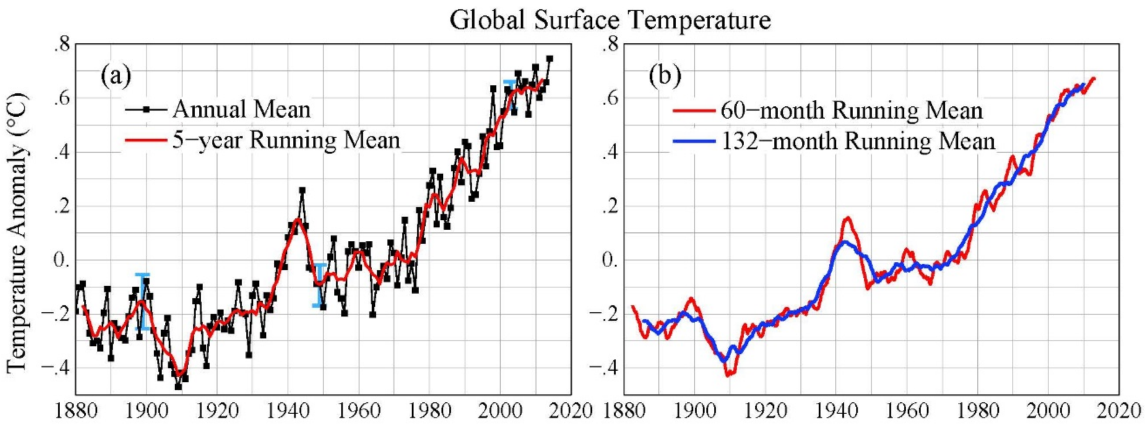


Chart 7: Global Surface Temperature Anomaly (60-Month And 132-Month Running Means) With A Base Period Of 1951-1980
Source: *Dangerous Climate Change* (Exhibit Sierra Club-JH-3 to this Declaration at Fig. 3), updated at http://www.columbia.edu/~mhs119/Temperature/.

Earth has now warmed about 0.9°C above the pre-industrial level. That is now close to, and probably slightly above, the prior maximum of the Holocene era – the period of relatively stable climate over the last 10,000 years that has enabled human civilization to develop. The warming increases Earth's radiation to space, thus reducing Earth's energy imbalance. However, because of the ocean's great thermal inertia, it requires centuries for the climate system to reach a new equilibrium consistent with a changed atmospheric composition. The planet's energy imbalance confirms that substantial additional warming is “in the pipeline”. That energy imbalance is now measured by an international fleet of more than 3000 submersible floats that plumb the depths of the world’s ocean measuring the increasing heat content.

Earth’s energy imbalance now averages about 0.6 Watts/m^2 averaged over the entire planet. I am uncertain whether this conveys to the Board the scale of what is going on. Alternatively, we can note that the total energy surplus is 300 trillion joules per second. That large number, however, may still be insufficiently evocative. Accordingly, we can observe, with equal validity, that Earth’s energy imbalance is equivalent to exploding more than 400,000 Hiroshima atomic bombs per day, 365 days per year. That is how much extra energy Earth is now gaining each day because of our use of the atmosphere as a waste dump for our carbon pollution.

Turning, now, to Chart 8, we can consider our present situation in the context of developments over the last 65 million or so years.

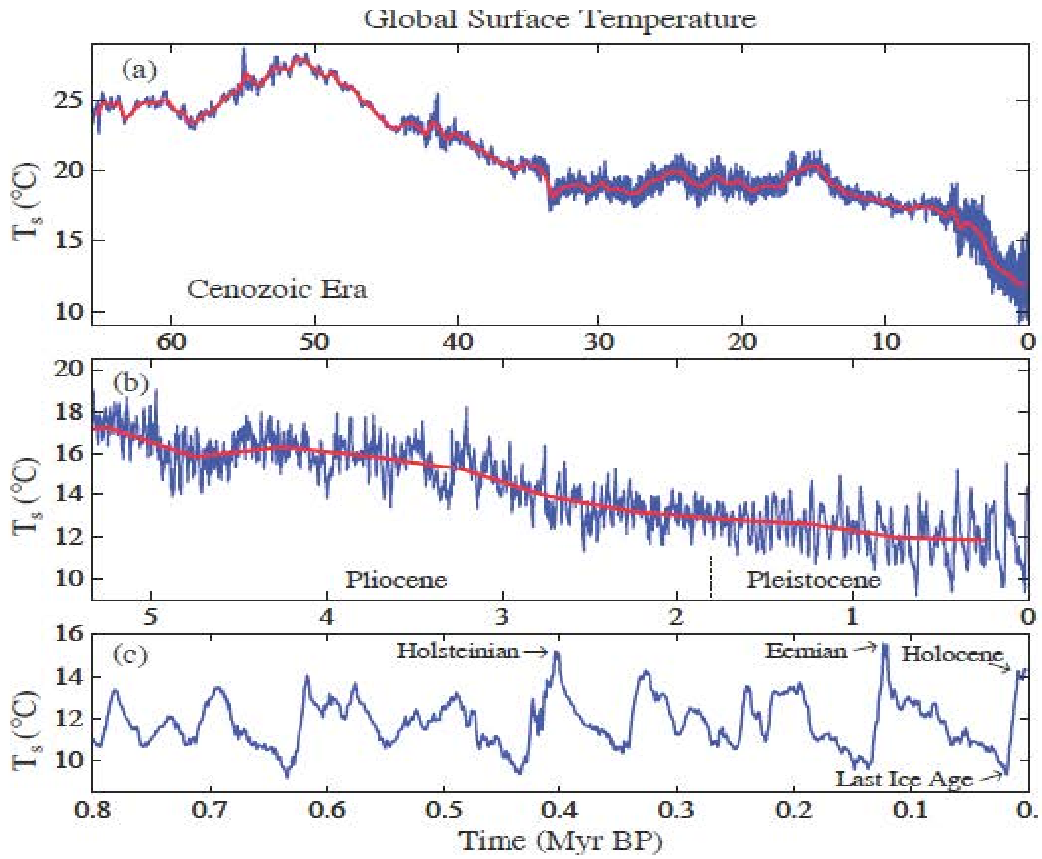


Chart 8: Surface Temperature Estimate for the Past 65.5 Myr, Including An Expanded Time Scale for (B) The Pliocene and Pleistocene and (C) The Past 800 000 Years
Source: J. Hansen, et al, *Climate Sensitivity, Sea level and Atmospheric Carbon Dioxide*,
Phil Trans R Soc A (2013), Fig. 4.

This record of average global surface temperature is based on high-resolution ice core data covering the most recent several hundred thousand years, and ocean cores on time scales of millions of years. It provides us with insight as to global temperature sensitivity to external forcings such as added CO_2, and sea level sensitivity to global temperature. It also provides quantitative information about so-called “slow” feedback processes –

such as melting ice sheets and lessened surface reflectivity attributable to darker surfaces resulting from melting ice sheets and reduced area of ice.

Several relevant conclusions can be drawn. First, the mechanisms that account for the relatively rapid oscillations between cold and warm climates were the same as those operating today. Those past climate oscillations were initiated not by fossil fuel burning, but by slow insolation changes attributable to perturbations of Earth's orbit and spin axis tilt. However, the mechanisms that caused these historical climate changes to be so large were two powerful amplifying feedbacks: the planet's surface albedo (its reflectivity, literally its whiteness) and atmospheric CO_2.

Second, the longer paleoclimate record shows that warming coincident with atmospheric CO_2 concentrations as low as 450 ppm may have been enough to melt most of Antarctica. Global fossil fuel emissions – towards which, as I noted above, our nation has contributed more than any other – have already driven up the atmospheric CO_2 concentration to approximately 400 ppm – up from 280 ppm of the preindustrial era.

I conclude from this, and other information, that the present level of CO_2 and its warming, both realized and latent, is already in the dangerous zone. Indeed, we are now in a period of overshoot, with early consequences that are already highly threatening and that will rise to unbearable unless action is taken without delay to restore energy balance at a lower atmospheric CO_2 amount.

Q. What do you mean by “unbearable?”

A. Let’s start with the ocean and sea level, in light of our most recent research.

Utilizing multiple lines of evidence – including satellite gravity measurement, surface mass balances, and satellite radar altimetry – it has become clear, regrettably, that ice mass losses from Greenland, West Antarctica and parts of East Antarctica are growing nonlinearly, with doubling times so far this century of approximately 10 years.

My colleagues and I now expect the exponential growth rate for ice mass loss in Greenland to slow, based on the most recent few years of data, but because of amplifying feedbacks described in our paper we also think it likely that Antarctic ice mass loss will continue to climb at its recent high exponent rate – again, if fossil fuel emissions are not rapidly abated. This prospect alone cries out for urgent national and international action to constrain carbon pollution, considering that complete disintegration of the Totten glacier in East Antarctica could raise sea levels by approximately 6-7m; that ice fronted by the Cook glacier in East Antarctica could add 3-4m of sea rise; and that West Antarctic ice fronted by Amundsen Sea glaciers have the potential to raise sea level an additional *3-4m*. *See* Exhibit Sierra Club-JH-4 at 41.

In the light of this and related information, we have concluded that humanity faces "nearly certainty of eventual sea level rise of at least . . . 5-9m if fossil fuel emissions continue on a business-as-usual course." *See* Exhibit Sierra Club-JH-4 at PDF page 31. Much of the U.S. eastern seaboard, as well as low-lying areas of Europe, the Indian sub-continent, and the Far East, would then be submerged. *See* Chart 9.

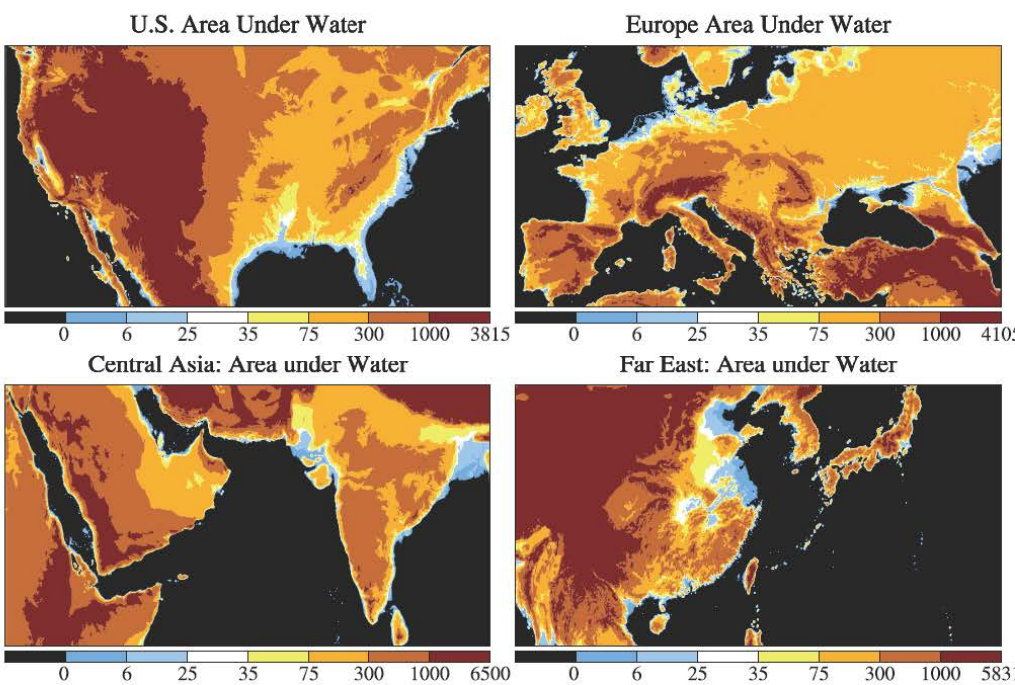


Chart 9: Areas (Light And Dark Blue) That Nominally Would Be Under Water For 6 And 25 M Sea Level Rise
Source: Climate Science, Awareness, and Solutions, Earth Institute, Columbia University (2015).

That order of sea level rise would result in the loss of hundreds of historical coastal cities worldwide, with incalculable economic consequences. It would also create hundreds of millions of global warming refugees from highly populated low-lying areas, and thus likely cause or exacerbate major international conflicts.[6]

That is what I mean by "unbearable."

To avoid such a calamity, sea level rise must be recognized as a key limit on any conceivably allowable human-made climate forcing and atmospheric CO_2 concentration, with fossil fuel emissions and land use changes constrained accordingly.[7] As discussed, ice sheet melting has now commenced even though global warming to

[6] In addition, strong temperature gradients caused by ice melt freshening is likely to increase baroclinicity and provide energy for more severe weather events, including in the North Atlantic. This set of circumstances will drive the powerful superstorms of our future. Some of these impacts are beginning to occur sooner in the real world than in our climate model. *See* Exhibit Sierra Club-JH-4 at pdf 31.

[7] This is so, as we wrote in "Ice Melt, Sea Level Rise and Superstorms," Exhibit Sierra Club-JH-4 at pdf 32, in light of the "extreme sensitivity of sea level to ocean warming and the devastating economic and humanitarian impacts of a multi-meter sea level rise."

date measures “only” 0.9°C above the pre-industrial period. This is consistent with the relevant paleoclimate evidence showing a multi-meter rise in sea level in the late Eemian period, approximately 125K years ago, when temperature was at most ~2^oC warmer than pre-industrial climate (at most ~1^oC warmer than today). This, in itself, and quite apart from the additional harm to terrestrial systems that must also be considered, implies that national and international goals and targets that aim to limit global warming to no more than 2^oC run an unacceptably high risk of global catastrophe.

An important effect for the coming period of large scale ice sheet melting, in our view, is that the discharge of ice and cold fresh water will expand sea ice cover and result in ocean surface, and regional cooling effects. *See* Exhibit Sierra Club-JH-4 at pdf 3-11. These effects temporarily mask some of the global warming, mainly in the North Atlantic and Southern Oceans, that would otherwise result from projected high CO_2 levels. The temporary surface cooling, however, would be coincident with a further increase in the planet’s energy imbalance, with added energy pumped into the ocean, and there be available, at Antarctica and Greenland, to further melt the subsurface shelves that, at present, restrain the planet’s major ice sheets at their grounding lines. *See* Exhibit Sierra Club-JH-4 at pdf 18.

Q. What are other impacts of global warming, besides sea level rise?

A. The impacts of global warming – including the renewed warming – will depend in part on the magnitude of Earth's energy imbalance, and that, in turn, will be controlled by the level of excess atmospheric CO_2. As I have noted already, global warming to date measures "only" 0.9°C above the pre-industrial period, and yet, that level of warming has already begun to have a widespread effect on natural and human systems.

For example, mountain glaciers, the source of fresh water to major world rivers during dry seasons, are receding rapidly all around the world. To cite a close-to-home example, glaciers in iconic Glacier National Park are in full retreat: In 1850, according to the Park Service, Glacier had 150 glaciers measuring larger than twenty-five acres. Today, it has just twenty-five.

As well, tropospheric water vapor and heavy precipitation events have increased, as we would expect. A warmer atmosphere holds more moisture, thus enabling precipitation to be heavier and cause more extreme flooding. Higher temperatures, on the other hand, increase evaporation and can intensify droughts when they occur, as can the expansion of the subtropics that occurs as a consequence of global warming.

Coral reef ecosystems, harboring more than 1,000,000 species as the “rainforests” of the ocean, are impacted by a combination of ocean warming, acidification from rising atmospheric CO_2, and other human-caused stresses, resulting in a 0.5-2% per year decline in geographic extent.

World health experts have concluded with “very high confidence” that climate change already contributes to the global burden of disease and premature death with expansion of infectious disease vectors. Increasing climate variability is being examined as a possible contributor to the expansion of Ebola.

Subtropical climate belts have expanded, contributing to more intense droughts, summer heat waves, and devastating wildfires. Further, summer mega-heat-waves, such as those in Europe in 2003, the Moscow area in 2010, Texas and Oklahoma in 2011, Greenland in 2012, Australia in 2013, Australia and California in 2014, and India, France and Spain this year (2015), have become more widespread. The probability of such extreme heat events has increased by several times because of global warming, and the probability will increase even further if fossil fuel emissions continue to be permitted, so that global warming becomes locked in and rendered increasingly severe.

I have already mentioned the unparalleled calamity that the loss of hundreds of coastal cities to rapid sea level rise presents to human civilization. But I should mention that many other impacts also will abound.

For example, acidification stemming from ocean uptake of a portion of increased atmospheric CO_2 will increasingly disrupt ocean ecosystem health, with potentially devastating impacts to certain nations and communities. Inland, fresh water security will be compromised, due to the effects of receding mountain glaciers and snowpack on seasonal freshwater availability of major rivers.

As to human health: increasing concentrations of CO_2 and associated increased global temperatures will deepen impacts, with children being especially vulnerable. Climate threats to health move through various pathways, including by placing additional stress on the availability of food, clean air, and clean water. Accordingly, unabated climate change will increase malnutrition and consequent disorders, including those related to child growth and development. It will increase death and illness associated with COPD, asthma, and other respiratory distress triggered by worsened allergies. Unabated emissions will also produce other injuries from heat waves; floods, storms, fires and droughts, and it will increase cardio-respiratory morbidity and mortality associated with increased ground-level ozone.

With regard to other species, we see that climate zones are already shifting at rates that exceed natural rates of change; this trend will continue as long as the planet is out of energy balance. As the shift of climate zones becomes comparable to the range of some species, the less mobile species will be driven to extinction. According to the UN Panel on Climate Change, with global warming of 1.6°C or more relative to pre-industrial levels, 9-31 percent of species are anticipated to be driven to extinction, while with global warming of 2.9°C, an estimated 21-52 percent of species will be driven to extinction. These temperature/extinction thresholds will not be avoided absent concerted, rational action on carbon emissions.

Q. But hasn't something like this happened before?

A. Not in the age of humankind, and the rate of change of atmospheric composition and consequent impacts far exceed any rate of change in Earth's history.

At present, we remain on track to burn a significant fraction of readily available fossil fuels, including coal, oil, natural gas, and tar sands, and so to raise average surface temperature, over time, to far above pre-industrial levels.

High global surface temperatures have been recorded previously, in the age of mammals, with some successful adaptation through evolution of higher surface-area-to-mass ratio body types – for example transient dwarfing of mammals and even soil fauna. However, human-made warming is occurring rapidly and will be fully realized in only centuries, as opposed to millennia, thus providing little opportunity for evolutionary dwarfism to alleviate impacts of global warming. Along with several colleagues, I have been forced to conclude that the large climate change that would result from burning all or most fossil fuels threatens the survival of humanity.

Q. Your testimony establishes that we have gone so far down this road, and you have pointed out that we have already driven atmospheric CO2 well into the danger zone. Is a human-caused calamity now inevitable and, if so, shouldn’t we just proceed with abandon to drill and pump and pipe/rail/truck our Bakken fuel to market?

A. No. There is a misconception that slow feedbacks associated with climate forcings already in place, including ice sheet disintegration, are now unstoppable.

That is simply not correct. Most slow feedbacks will never occur, if we succeed in restoring Earth's energy balance. Accordingly, restoration of our climate system, and thus, protection of our children's future, is still possible if we act with reason, courage, and no further delay.

As I indicated above, the energy imbalance of Earth is about 0.6 W/m^2. In the light of that imbalance, colleagues and I have calculated the level to which atmospheric CO_2 must be drawn down in order to increase Earth's heat radiation to space by the same amount and thus restore energy balance – the fundamental requirement to stabilize climate and avoid further dangerous warming.

The measured energy imbalance indicates that CO_2 must be reduced to a level below 350 ppm, assuming that the net of other human-made climate forcings remains at today's level.

Let us return, for a moment, to Chart 5, so as to consider again the question of delay. On the left side of the chart, the long-residence time for atmospheric CO_2 is illustrated. It is reflected in the length of time it would take to return CO_2 to lower concentrations even if, as indicated on the right side of the chart, fossil fuel emissions were to cease entirely.

Q. But isn't an abrupt cessation of all CO_2 emissions, whether this year or in 2030, unrealistic? Indeed, here we are, with all this knowledge of the dangers of unarrested climate change at our fingertips -- and *still* we argue over whether a company should be allowed to massively *expand* exploitation of the Bakken oil reserves.

A. It is correct that industry, other business, and consumers all need time to retool and reinvest in emission-free options to fossil fuels. But government agencies can assist markedly right now by denying permits for additional exploitation that would serve only to cut short the time available for that necessary transition.

To assist in that transition, my colleagues and I evaluated emissions reduction scenarios to devise a path that is both technically and economically feasible, while being sufficiently rigorous to constrain the period of "carbon overshoot" and avoid calamitous consequences (greatly accelerated warming, ecosystem collapse, and widespread species extermination). *See* Chart 10.

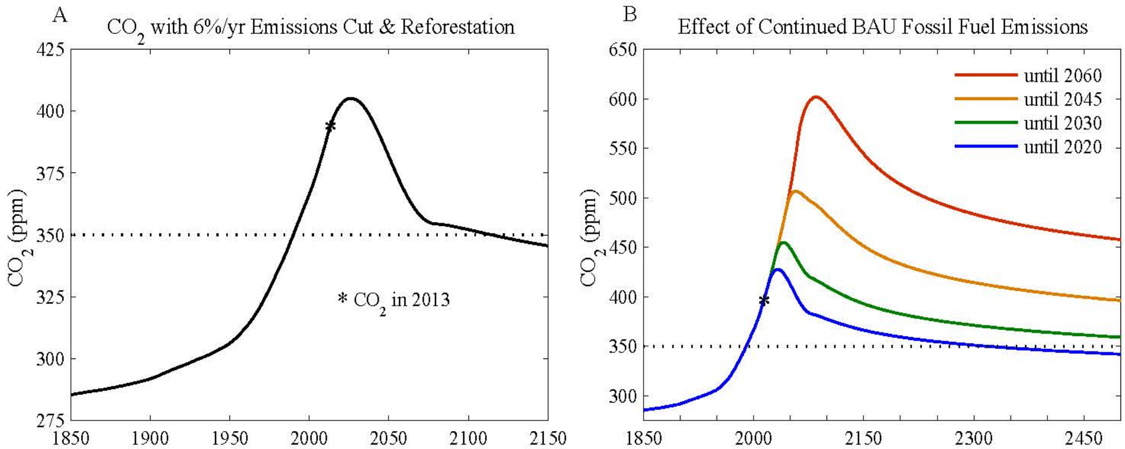


Chart 10: Atmospheric CO_2 If Fossil Fuel Emissions Are Reduced.
(A) 6% Or 2% Annual Cut Begins In 2013 And 100 GRC Reforestation Drawdown Occurs In 2031-2080, (B) Effect Of Delaying Onset Of Emission Reductions.
Source: *Dangerous Climate Change* (Exhibit Sierra Club-JH-3 to this Testimony at Fig. 5).

Our analysis prescribes a glide path towards achieving energy balance by the end of the century. It is characterized by large, long-term global emissions reductions (of approximately 6 percent annually, if commenced this year), coupled with programs to limit and reverse land use emissions via reforestation and improved agricultural and forestry practices (drawing down approximately 100 GtC by the year 2100).

These actions would not be easy, but they are feasible and could achieve the goal of restoring the atmosphere to approximately 350 ppm within this century if commenced without further delay, and then adhered to. As I have indicated, such action is minimally needed to restore earth's energy balance, preserve the planet's climate system, and avert irretrievable damage to human and natural systems – including agriculture, ocean fisheries, and fresh water supply – on which civilization depends.

However, consistent with the abrupt phase out scenarios discussed in the prior paragraph, if rapid annual emissions reductions are delayed until 2030, then the global temperature will remain more than 1°C higher than preindustrial levels for about 400 years. Were the emissions cessation only to commence after 40 years, then the atmosphere would not return to 350 ppm CO_2 for nearly 1000 years. Overshooting the safe level of atmospheric CO_2 and the safe range of global ambient temperature for anything approaching these periods will consign succeeding generations to a vastly different, less hospitable planet.

Considered another way, the required rate of emissions reduction would have been about 3.5% per year if reductions had started in 2005 and continued annually thereafter, while the required rate of reduction, if commenced in 2020, will be approximately 15% per year. Accordingly, the dominant factor is the date at which fossil fuel emission phase out begins, again presuming the rate of annual emissions reductions thereafter are sustained.

Q. But how can we get from here to there? That is, how can we turn from our present road to calamity onto a path that restores atmospheric CO_2 to less than 350ppm, so that energy balance is achieved, before the ice sheets disintegrate?

A. The essential step, in my view -- and that of other experts, including economists[8] -- is an accord establishing a growing price on CO_2 emissions, which would lead over time to their phase-out. Agreement upon such a domestic fee by major emitters, most notably the United States and China, with a border duty on products from nations that do not have an equivalent domestic carbon fee, would be expected to lead to widespread global movement toward carbon-free energies.

In theory, a U.S. state also could impose such a fee upon the emissions of fossil fuels consumed in-boundary or burned externally for electricity imported into the state. Revenues could be returned through dividends to the people on a per-capita basis, so as to offset any associated

[8] These include three co-authors of our 2013 PLOS One study. *See* Sierra Club-JH-3. The government also has understood the central importance of a rising carbon price, for at least 25 years. *See*, e.g., Congressional Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases* (1991) at 15 ("a particularly effective way of targeting the heaviest economic sanctions against the worst emitters of CO_2."). As colleagues and I noted in 2013, Sierra Club-JH-3 at 19, "[a] rising carbon fee is the *sine qua non* for fossil fuel phase out."

increase in energy costs. In this way, a meaningful incentive for a transition to non-fossil energy reliance would be established.

But, in the absence of such a serious program, every additional or expanded fossil fuel project serves only to undermine the opportunity and shorten the time remaining to preserve a habitable future for our children and their progeny. In such a context, there is no reasonable option but to withhold authorization.

Q. Does this conclude your prepared testimony?

A. It does. At the Board's request, I will be pleased to elaborate on any of the points I have made herein.