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UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA
SAN FRANCISCO DIVISION

ALEC L., *et al.*, Plaintiffs, vs. LISA JACKSON, *et al.*, Defendants.	Case No.: 4:11-cv-02203 EMC **Brief for Amicus Curiae Dr. James Hansen** **(Hon. Edward M. Chen)**

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INTEREST AND IDENTITY OF *AMICUS CURIAE* JAMES HANSEN

Amicus Curiae James Hansen, Ph.D., appears here in his individual capacity and not as a representative of any institution with which he is affiliated. The information and opinions in this brief are not necessarily those of any institution with which he is affiliated or those of any party to the present litigation. This brief is offered as an aid to the Court's deliberations over whether the relief sought by plaintiffs in their motion for preliminary injunction is needed to preserve a climate system that is conducive to the survival and wellbeing of our children and their progeny.

Dr. James Hansen directs the NASA Goddard Institute for Space Studies in New York City and is an Adjunct Professor of Earth Sciences at Columbia University's Earth Institute. He was trained in physics and astronomy in the space science program of Dr. James Van Allen at the University of Iowa, receiving his Ph. D. in physics in 1967. Since the mid-1970s, Dr. Hansen has focused on computer simulations and studies of the Earth's climate, for the purpose of understanding the human impact on global climate. Dr. Hansen's testimony to Congress in the 1980s helped raise broad awareness of the global warming issue. In recent years Dr. Hansen has drawn attention to the danger of passing climate tipping points, producing irreversible climate impacts that would yield a different planet from the one on which civilization developed. As part of his work in recent years, Dr. Hansen has outlined steps that are needed to stabilize climate, with a cleaner atmosphere and ocean.

Dr. Hansen was elected to the National Academy of Sciences in 1995.

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SUMMARY OF ARGUMENT

Global warming due to emissions of greenhouse gases, mainly CO_2 from fossil fuel consumption, is already 0.8°C, and a similar or greater amount is "in the pipeline" without any further change of atmospheric composition. Already-observed impacts of this warming include rising sea levels, increased atmospheric moisture resulting in more intense precipitation events, higher temperatures causing more frequent and intense heat waves and droughts, loss of sea ice, ice sheet mass and glaciers, expansion of the subtropics, acidification of the oceans, shifting distributions of plant and animal species, and an increasing rate of species extinctions.

Maintaining a climate that resembles the Holocene epoch, the world of a relatively stable climate system under which civilization developed, requires rapid reduction of fossil fuel CO_2 emissions and reforestation. Atmospheric CO_2 concentrations passed the level that is estimated to be safe on the long term in, approximately, 1988; global mean temperature now exceeds the Holocene peak; and unabated fossil fuel emissions continue to drive the Earth increasingly out of energy balance. Unless action is undertaken without further delay, so as to return the atmospheric concentration of CO_2 to 350ppm by 2100, Earth's climate system will be pressed toward and past points of no return. Effective action remains possible, but delay in undertaking sharp reductions in emissions will undermine any realistic chance of preserving a habitable climate system -- needed by future generations no less than by prior generations.

Plaintiffs in this case seek a preliminary injunction to ensure that Defendants in this matter submit to the Court a plan to preserve the climate system, including a cap on CO_2 emissions at 2011 levels by 2013, and emissions reductions thereafter by a minimum of 6% annually. That prescription is consistent with scientific understanding of what is minimally needed to avert truly dangerous climate change and preserve the physical status quo of a habitable climate system. In light of the fossil fuel industry's stranglehold of Congress, the President's demonstrated disinclination to utilize his authority to act, and the fact that further delay vastly increases the risk of irretrievable damage to the climate system, action by this Court now is essential.

ARGUMENT

I. INTRODUCTION: THE RELEVANT STATUS QUO IS AN ATMOSPHERE THAT ENSURES A HABITABLE CLIMATE SYSTEM.

Plaintiffs and Defendants both appeal to the Court to preserve the "status quo." Pl's Mot'n for Prelim. Inj at 10; Def. Opp'n to Pl. Mot'n for Prelim. Inj. at 9. Amicus James Hansen also seeks to preserve the status quo; accordingly, this brief begins with an explanation as to what this implies for the global climate system.

Paleoclimate research conducted by Dr. Hansen and others establishes that for most of the Holocene period – the period of the most recent 10,000 years – Earth's climate, though highly variable on a regional basis, has been characterized by reasonably constant mean global temperatures. James Hansen et al., The Case for Young People and Nature: A Path to a Healthy, Natural, Prosperous Future (attached hereto as Exhibit 1) at 6.[1] This constancy enabled the Greenland and Antarctic ice sheets to remain in near mass balance, sea levels to be relatively stable, species to diversify, and civilization to develop.

Largely due to the burning of fossil fuels, the atmospheric CO_2 concentration has climbed sharply in recent decades – from 316ppm in 1959 to 390ppm in 2010.[2] In that period, US CO_2 emissions more than doubled, from 2.83 to 5.67 billion metric tons.[3] The CO_2 concentration is now to a level not seen on Earth for at least 3 million years. Exhibit 1 at 6. The CO_2 increment functions as an added blanket on the planet, reducing the amount of heat that would otherwise be re-radiated to space and throwing the planet into energy imbalance. In response, Earth has warmed by approximately $0.8^{o}C$ over the last century, likely exceeding the prior Holocene peak.

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[1] *See also*, James Hansen and Makiko Sato, Paleoclimate Implications for Human-Made Climate Change 8-14 (2011).

[2] Mauna Loa CO_2 annual mean data from http://www.esrl.noaa.gov/gmd/ccgg/trends/.

[3] Carbon Dioxide Information Analysis Center (CDIAC), National CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2008, http://cdiac.ornl.gov/ftp/trends/emissions/usa.dat. The text of this amicus brief here provides the data in units of CO_2 by utilizing the CDIAC's carbon-to-CO_2 conversion factor of 3.667.

Exhibit 1 at 7-8. The already apparent impact of this warming is reviewed in the next section. Due to Earth's thermal inertia, a similar or greater amount of additional 2.0°C warming is "in the pipeline" before Earth reaches energy balance at the present level of atmospheric CO_2 concentration.[4]

Avoidance of climate tipping points and subsequent points of no return[5] requires effective action to return the atmospheric CO_2 concentration to approximately 350ppm by the end of the century. *Exhibit 1* at 8. This would allow additional heat radiation to escape to space so as to restore the planet's energy balance without additional prolonged global warming. *Id*. Such action could stabilize Earth's climate system and mitigate human suffering, but further delay may doom this prospect.

The relevant status quo with respect to the present litigation, therefore, is an atmosphere whose composition of greenhouse gases ensures a relatively stable climate system conducive to the survival and well being of humanity and nature. This requires, then, action to restore the atmospheric CO_2 concentration to no more than 350ppm. In that we have currently overshot this safe atmospheric concentration level, as discussed *infra*, failure to act with all deliberate speed in the face of the clear scientific evidence of the danger[6] functionally becomes a decision to eliminate the option of preserving a habitable climate system.

II. GLOBAL WARMING HAS ALREADY REACHED THE DANGEROUS LEVEL AND, WITHOUT EFFECTIVE ACTION, WILL PRODUCE CATASTROPHIC AND IRRETRIEVABLE LOSSES.

Global climate change does not present merely "the possibility of some remote future injury." Def. Opp'n to Pl. Motion for Prelim. Inj at 9. Instead, it is a phenomenon that is already undermining human and natural systems, causing loss of life, and pressing species to extinction.

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[4] Hansen et al, Target Atmospheric CO_2: Where Should Humanity Aim?, hereinafter referred to as "Target CO_2," 225, The Open Atmospheric Science Journal (2008).

[5] *Id*.

[6] J. Hansen et al., Dangerous human-made interference with climate, Atmos. Chem. Phys., 7, 2287, 2308 (2007)

Unless arrested by effective action, climate change will produce calamitous consequences for humanity and nature alike, as tipping points are reached and points of no return are crossed.[7] Present and future impacts are addressed in turn.

(a) Present Impacts

While, as noted, global warming to date measures 0.8°C above the 1880-1920 period,[8] it has already led to a 40 percent reduction and an accelerating downward trend in summer Arctic sea ice cover, and an even faster decline in its thickness. *Exhibit 1* at 4. Continental ice sheets of Greenland and Antarctica have begun to shed ice at a rate of several hundred cubic kilometers per year. *Id*. In the past decade, sea level increased about 3cm—a rate of about one foot per century, and nearly twice as fast as the rate of increase during the preceding century.[9] This rise has resulted in losses of coastal wetland areas and greater levels of damage from coastal flooding.[10] For example, in the United States, increased sea level has led to the loss of 1900 square miles of coastal wetland in Louisiana, which in turn exacerbates the area's vulnerability to storm surges like Hurricane Katrina.[11] Mountain glaciers, the source of fresh water to major world rivers during the dry season, are receding rapidly all around the world. *Exhibit 1* at 4. In 1850, Glacier National Park in Montana had 150 glaciers measuring larger than twenty-five acres—today, it has just twenty-five.[12]

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[7] Hansen, et al define "the tipping level [as] the global climate forcing that, if long maintained, gives rise to a specific consequence [and] the point of no return [as] a climate state beyond which the consequence is inevitable, even if climate forcings are reduced. Target CO_2 at 225.

[8] The 1880-1920 period is the earliest time at which instrumental data allows accurate specification of global temperature, and the temperature in that period is estimated to be close to pre-industrial temperature averaged over several centuries.

[9] Decl. James Hansen at ¶ 40, 2006 WL 4761053 (D. Vt. 2006).

[10] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2007: IMPACTS, ADAPTATION, AND VULNERABILITY, Table 4.1 (hereinafter "IPCC Working Group II").

[11] U.S. Global Change Research Program, 2009: *Global Climate Change Impacts in the United States*, T. Karl, J.M. Melillo, T.C. Peterson (eds.), Cambridge Univ. Press.

[12] Brief of Amici Curiae Climate Scientists James Hansen et al., *Chamber of Commerce of the United States v. EPA*, 2010 WL __ (*citing to* U.S. Geological Survey, *Melting Glaciers Signal Change in National Parks*, http://www.nwrc.usgs.gov/world/content/land5.html).

Tropospheric water vapor and heavy precipitation events have increased. Droughts are more common, especially in the tropics and subtropics. *Exhibit 1* at 4. Coral reef ecosystems are being impacted by a combination of ocean warming and acidification from rising atmospheric CO_2, resulting in a 1-2% per year decline in geographic extent. *Exhibit 1* at 4. World health experts have concluded with "very high confidence" that climate change already contributes to the global burden of disease and premature death with altered distribution of some infectious disease vectors.[13] Subtropical climate belts have expanded, contributing to more intense droughts, summer heat waves, and devastating wildfires in the southern United States, the Mediterranean and Middle East regions, and Australia. *Exhibit 1* at 4. Mega-heat waves have become noticeably more frequent, including the 2010 heat wave in Moscow and in Texas in 2011. *Exhibit 1* at 4. It is nearly certain that such "outlier" heat events would not have occurred in the absence of global warming.[14]

(b) Future effects

Scientific prediction of long-term impacts from climate change is imprecise in part because of uncertainty about the relative speed with which amplifying feedbacks, including disintegration of Earth's major ice sheets, will occur. *Exhibit 1* at 13. Citing the Paleoclimate record, Dr. Hansen and colleagues noted the following most recently:

> Precise consequences of continuing [business as usual] emissions for several decades are difficult to define, because Earth has never experienced such a large rapid increase of climate forcings as would occur with burning of most fossil fuels this century. The closest analogy in Earth's history is probably the PETM (Paleocene-Eocene Thermal Maximum) in which rapid global warming of at least 5°C occurred. The PETM warming spike occurred in conjunction with injection of 3000-5000 GtC of carbon into the surface climate system during two 1-2 thousand year intervals separated by several thousand years. It is often assumed that the carbon originated from melting of methane hydrates, because of the absence of other known sources of that magnitude. PETM occurred during a 10-million year period of slow global warming, and thus methane release might have been a feedback magnifying that warming.
>
> The PETM witnessed extinction of about half of small shelled deep ocean

[13] IPCC Working Group II.

[14] J. Hansen, M. Sato, R. Ruedy, Climate Variability and Climate Change: The New Climate Dice, Nov. 10, 2011.

> animals that serve as a biological indicator for ocean life in general, but, unlike several other large warming events in Earth's history, there was little extinction of land plants and animals. An important point is that the magnitude of the PETM carbon injection and warming is comparable to what will occur if humanity burns most of the fossil fuels, but the human-made warming is occurring 10-100 times faster. The ability of life on Earth today to sustain a climate shock comparable to the PETM but occurring 10-100 times faster is highly problematic. Climate zones would be shifting much faster than species have ever faced. Thus if humanity burns most of the fossil fuels, Earth, and all species residing on it, will be pushed into uncharted climate change territory.

Exhibit 1 at 13 (internal citations omitted).

Based on measurements of observed climate change, computer simulations of the climate system's responses to additional CO_2 emissions, as well as information from the paleoclimate record, Dr. Hansen and others have concluded that continued burning over several decades of fossil fuels renders multi-meter sea level rise "practically certain," and create cause "millions of global warming refugees from highly populated low-lying areas . . . throwing existing global demographics into chaos." *Exhibit 1* at 14 (internal citations omitted).

These researchers note, as well, that acidification stemming from ocean uptake of a portion of increased atmospheric CO_2 is expected to increasingly disrupt coral reef ecosystem health, with potentially devastating impacts to certain nations and communities. *Exhibit 1* at 16. Hansen and others warn of receding mountain glaciers "with effects on seasonal freshwater availability of major rivers," *Exhibit 1* at 4, illustrating that present atmospheric CO_2 leves are "already a threat for future fresh water security." *Id*. at 16.

Increased concentration of CO_2 and associated increased global temperatures will deepen impacts on human health, with children being especially vulnerable. *Exhibit 1* at 16. Climate threats to health move through various pathways, especially by placing additional stress on the availability of food, clean air, and clean water. *Exhibit 1* at 16 (*citing to* Bernstein and Myers, *Climate Change and Children's Health*, Current Opin. Pediatrics, 23, 221-226 (2011)). Other principle climate-related impacts on human health include heat waves, asthma and allergies, infectious disease spread, drought, pests and disease spread across taxa: forests, crops and marine life, and winter weather anomalies. *Exhibit 1* at 18 (Table 1).

As noted *supra*, 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, a conclusion "based on comparison of the observed trend with inter-decadal variability in climate simulations."[15] Dr. Hansen and others note that "as the shift of climate zones becomes comparable to the range of some species, the less mobile species will be driven to extinction." *Exhibit 1* at 15. In 2007, the Intergovernmental Panel on Climate Change (IPCC) summarized studies estimating species extinctions from additional global warming and estimated[16] that for global warming of 1.6^{o}C or more, relative to pre-industrial levels, 9-31 percent of species will be driven to extinction, while with global warming of 2.9^{o}C, an estimated 21-52 percent of species will be driven to extinction.[17]

III. ACTION TO PHASE OUT CO_2 EMISSIONS IS URGENTLY REQUIRED, WHILE DELAY VIRTUALLY ENSURES CALAMITY.

The 2007 consensus statement by the IPCC, summarizing research through 2005, indicated that human-induced warming of Earth of approximately 2^{o}C constituted dangerous climate change. From that, however, no conclusion logically could be drawn as to the danger inherent in lower levels of global warming.

Research by Dr. Hansen and others to assess this question has been spurred on by the realization, as described *supra*, that large climate impacts have commenced already, even though Earth's lagged temperature response to the recent climb in atmospheric CO_2 is only 0.75^{o}C above preindustrial levels. Hansen et al estimate that this warming is already at least 0.25^{o}C above the prior Holocene maximum. *Exhibit 1* at 5. Empirical research showing an ongoing and

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[15] Hansen, J., M. Sato, R. Ruedy, *et al.*, 2007b: Dangerous human-made interference with climate: a GISS modelE study, *Atmos. Chem. & Phys.*, **7**, 2287-2312.

[16] IPCC Working Group II.

[17] Hansen et al note that "mass extinctions have occurred in conjunction with rapid climate change during Earth's long history. While new species evolved over hundreds of thousands and millions of years, such time scales are almost beyond human comprehension. Accordingly, if we drive many species to extinction we will leave a more desolate planet for our children, grandchildren, and as many generations as we can imagine." *Exhibit 1* at 15.

accelerating mass loss of the Greenland and West Antarctic ice sheets, which began within the last few decades, provides strong confirmation that today's global temperature has reached a level higher than prior Holocene temperatures. *Id*.

Accordingly, the best available current science establishes that today's global temperature is already close to or into the "dangerous zone." *Exhibit 1* at 106. Because the recently-observed climate effects with respect to the ice sheets are still relatively small compared to total ice sheet mass, these feedbacks may not be a major factor if maximum global warming overshoot of ~1^{o}C occurs only briefly and then recedes. *Exhibit 1* at 10-12.

Action therefore must be undertaken to restore the atmosphere's safe level of CO_2 concentration to 350ppm, so as to avert any avoidable additional warming that may drive the climate system past tipping points "that assure transition to a very different planet," *Id*. at 12, and keep the period of overshoot to an absolute minimum.

Two underlying reasons that such action must be undertaken without further delay is indicated in Amicus Hansen's most recent research, summarized here, and illustrated in Fig. 1 *infra*. First, a substantial share of any additional infusion of CO_2 lasts in the atmosphere for centuries (and while there, continuously acts to further heat the planet). Accordingly, Earth's temperature response to the "radiative forcing" effect of the higher atmospheric CO_2 concentration is a function not only of recent emissions, but the persisting share of prior emissions. Second, as a consequence of the long-lived nature of CO_2 and the fact that human-derived emissions have already cause a substantial overshoot of the long-term safe atmospheric concentration level, any substantial delay in undertaking effective action – even if such action compelled a sharp cut-off of emissions – would render it impossible to return the atmospheric CO_2 concentration to 350ppm within this century. Thus, as illustrated in Fig. 1b, if emissions of CO_2 are allowed per business as usual for even two decades longer the concentration of CO_2 in the atmosphere will not return, until the year 2150, to the nominally safe level of 350ppm even if all such emissions were abruptly ceased in the year 2030.[18] In contrast, complete cessation in 2011 would return to the atmospheric CO_2 concentration to 350ppm by mid-century. *Exhibit 1* at 9.

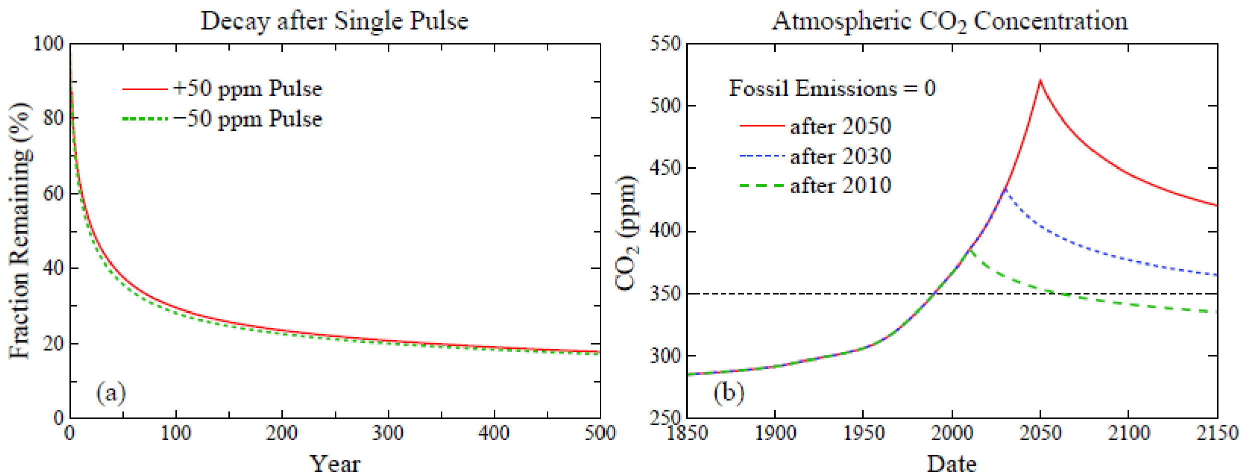

Figure 1. (a) Decay of instantaneous (pulse) injection and extraction of atmospheric CO_2, (b) CO_2 amount if fossil fuel emissions are suddenly terminated at the end of 2010, 2030, 2050. (Hansen et al., The Case for Young People and Nature: A Path to a Health, Natural, Prosperous Future.)

An abrupt cessation of all CO_2, whether in 2011 or 2030, is unrealistic, in part because industry, other business, and consumers alike need time to retool and reinvest in emission-free options to fossil fuels. Accordingly, Hansen et al have proposed a glide path to secure an atmosphere whose CO_2 concentration is no higher that 350ppm. Their plan requires emission reductions of 6 percent annually, coupled with a program of reforestation. *Exhibit 1* at 10. This will achieve the goal of restoring the atmosphere to approximately 350ppm if the plan is commenced without delay, and then adhered to. However, consistent with the abrupt phase out scenarios discussed in the prior paragraph *supra*, if the 6 percent annual emission reductions are delayed until 2030, then the global temperature will remain above 1^{o}C higher than preindustrial

[18] *Exhibit 1* at 9. Further, were the emission cessation to commence only after 40 years, Dr. Hansen estimates that the atmosphere would not return to 350ppm CO_2 for nearly a 1000 years. *Id.*

levels for nearly 300 years. It would be "highly unlikely," that the planet's major ice sheets would remain "stable at their present size with such long-lasting warmth." *Exhibit 1* at 12-13.

Considered in another way, the required rate of emissions reduction would have been about 3.5% per year if reductions had started in 2005, while the required rate of reduction, if commenced in 2020, will be approximately 15% per year. *Id.* at 6. This illustrates, again, that "the dominant factor, by far, is the date at which fossil fuel emission phase-out begins." *Id.* at 11.

The present danger and impending calamities presented by continued CO_2 emissions, and the urgent need to get beyond fossil fuels before Earth is altered in fundamental respects – including its ability to sustain civilization – renders it a first-order tragedy that all serious attempts to address the problem in Congress to date either have been still-borne or killed after some debate. Equally tragic, the executive branch, including our current president, has declined to act with any degree of effectiveness to restrict CO_2 and other greenhouse gas emissions from the largest sources – bowing to industry pressure at virtually every turn even though, pursuant to the Supreme Court's leading global warming decision, *Mass. v. EPA*, 549 U.S. 497 (2007), it retains authority to act. The "absence of effective leadership" is attributable, as Amicus Hansen points out, to the "undue sway of special financial interests on government policies."[19] In the absence of political leadership, an Order by this Court granting the injunctive relief sought by plaintiffs in this matter may be the best, the last, and, at this late stage, the only real chance to preserve and restore the atmosphere and climate system.

CONCLUSION

Systematic reductions in CO_2 emissions, for the reasons provided by Dr. Hansen in his work cited throughout this amicus brief, must be undertaken in conjunction with reforestation so as to return the concentration of CO_2 in the atmospheric to a level no higher than 350ppm by the end of the century, if not sooner. Plaintiffs in this matter seek an Order by the Court to require Defendants to submit a "Climate Recovery Plan" by next March whose key features, if followed,

[19] *Exhibit 1* at 10 (citing to Oreskes, N.; Conway, E.M., 2010: Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming. Bloomsbury Press, 355 pp. merchantsofdoubt.org.).

will restore the atmosphere and preserve a habitable climate system. This brief has established that such action is urgently required. In particular, the failure to commence CO_2 reductions without further delay, and to undertake other measures consistent with the prescription developed by Dr. Hansen and others, and advanced in these proceedings by Plaintiffs, would consign our children and their progeny to a very different planet, one far less conducive to their survival.

Respectfully submitted this 14th day of November, 2011.

__/s/____________________________________

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Exhibit 1
The Case for Young People and Nature:
A Path to a Healthy, Natural, Prosperous Future
By James Hansen et al., 2011

The Case for Young People and Nature: A Path to a Healthy, Natural, Prosperous Future

James Hansen[1], Pushker Kharecha[1], Makiko Sato[1], Frank Ackerman[2], Paul R. Epstein[3], Paul J. Hearty[4], Ove Hoegh-Guldberg[5], Shi-Ling Hsu[6], Camille Parmesan[7], Stefan Rahmstorf[8], Johan Rockstrom[9], Eelco J. Rohling[10], Jeffrey Sachs[1], Pete Smith[11], Konrad Steffen[12], Karina von Schuckmann[13], James C. Zachos[14],

Abstract. Global warming due to human-made gases, mainly CO_2, is already 0.8°C and deleterious climate impacts are growing worldwide. More warming is 'in the pipeline' because Earth is out of energy balance, with absorbed solar energy exceeding planetary heat radiation. Maintaining a climate that resembles the Holocene, the world of stable shorelines in which civilization developed, requires rapidly reducing fossil fuel CO_2 emissions. Such a scenario is economically sensible and has multiple benefits for humanity and other species. Yet fossil fuel extraction is expanding, including highly carbon-intensive sources that can push the climate system beyond tipping points such that amplifying feedbacks drive further climate change that is practically out of humanity's control. This situation raises profound moral issues as young people, future generations, and nature, with no possibility of protecting their future well-being, will bear the principal consequences of actions and inactions of today's adults.

Humanity is now the dominant force driving changes of Earth's atmospheric composition and thus future climate (IPCC, 2007a). The principal climate forcing is carbon dioxide (CO_2) from fossil fuel emissions, much of which will remain in the atmosphere for millennia (Archer, 2005; IPCC, 2007a). The climate system's inertia, which is mainly due to the ocean and the ice sheets on Greenland and Antarctica, causes climate to respond slowly, at least initially, but in a very long-lasting way to this human-made forcing.

Governments have recognized the need to limit emissions to avoid dangerous human-made climate change, as formalized in the Framework Convention on Climate Change (FCCC, 1992). Despite this, the Kyoto Protocol, established in 1997 to reduce developed country emissions and slow emissions growth in developing countries, has been so ineffective that the rate of global emissions has since accelerated to almost 3%/year, compared to 1.5%/year in the preceding two decades (Reference).

There is a huge gap between rhetoric about reducing emissions and reality. Governments and businesses offer assurances that they are working to reduce emissions, but only a few nations have made substantial progress. Reality (Krauss, 2010) exposes massive efforts to expand fossil fuel extraction, including oil drilling to increasing ocean depths, into the Arctic, and onto environmentally fragile public lands; squeezing of oil from tar sands and tar shale; hydro-

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[12] Cooperative Institute for Research in Environmental Sciences, University of Colorado
[13] Centre National de la Recherche Scientifique, LOCEAN, Paris (hosted by Ifremer, Brest), France
[14] Earth and Planetary Science, University of California at Santa Cruz

fracking to expand extraction of natural gas; and increased mining of coal via mechanized longwall mining and mountain-top removal.

Governments not only allow this activity, but use public funds to subsidize fossil fuels at a rate of about 500 billion US$ per year[15]. Nor are fossil fuels required to pay their costs to society. Air and water pollution due to extraction and burning of fossil fuels kills more than 1,000,000 people per year and affects the health of billions of people (Cohen et al., 2005). But the greatest costs to society are likely to be the impacts of climate change, which are already apparent and are expected to grow considerably (IPCC, 2007b; Ackerman and Stanton, 2011).

Climate change is a moral issue of unprecedented scope, a matter of intergenerational injustice, as today's adults obtain benefits of fossil fuel use, while consequences are felt mainly by young people and future generations. In addition, developed countries are most responsible for emissions, but people in less developed countries and indigenous people across the world are likely to be burdened the most while being least able to adapt to a changing climate.

The tragedy of human-made climate change, should the rush to exploit all fossil fuels continue, is that transition to clean energies and energy efficiency is not only feasible but economically sensible (Stern, 2007: Ackerman et al., 2009; Hsu, 2011). Assertions that phase-out of fossil fuels would be unacceptably costly can be traced to biased assumptions that do not account for the costs of fossil fuels to society or include the benefits of technology innovations that would emerge in response to an appropriate price on carbon emissions.

Our aim here is to clarify the urgency to phase out fossil fuel emissions. We summarize the emission reductions required to restore Earth's energy balance, which is the basic requirement for stabilizing climate. We also draw attention to the moral issues, our obligations to young people, future generations, less developed nations, indigenous people, and our fellow species.

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[15] http://www.iea.org/weo/docs/G20_Subsidy_Joint_Report.pdf
and http://www.hedon.info/docs/GSI_The-Politics-Of-Fossil-Fuel-Subsidies.pdf

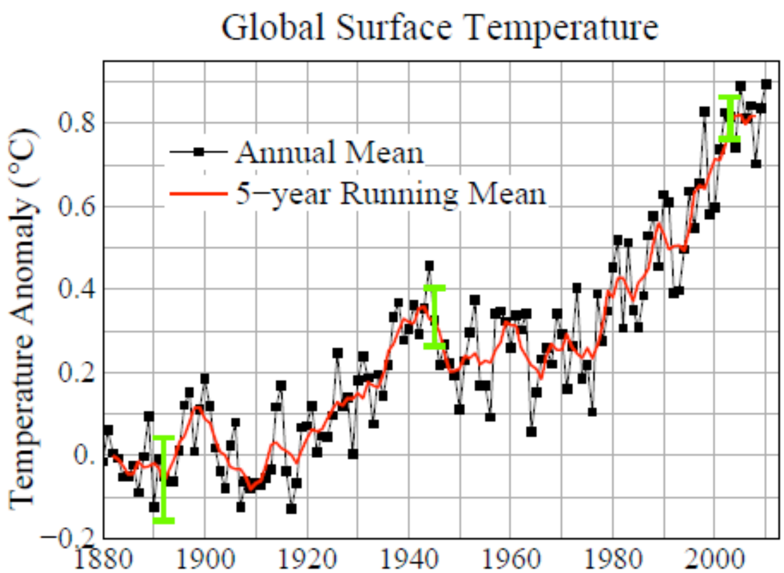

Fig. 1. Global surface temperature anomalies relative to 1880-1920 mean. Green bars are 95% confidence intervals (Hansen et al., 2010).

Global Temperature

Global surface temperature fluctuates chaotically and also responds to natural and human-made climate forcings. Forcings are imposed perturbations of Earth's energy balance such as changes of the sun's luminosity and human-made increase of atmospheric CO_2 from fossil fuel burning.

Modern Temperature. Temperature change in the past century (Fig. 1) includes unforced chaotic variability and forced climate change. Global warmth in 1998 was due to the strongest El Niño of the century, a natural warming in the tropics caused by a fluctuation of ocean dynamics. Cooling in 1992 was due to stratospheric aerosols from the Mount Pinatubo volcanic eruption, which reduced sunlight reaching Earth's surface as much as 2%. The long-term global warming trend is at least predominately a forced climate change caused by increased human-made atmospheric greenhouse gases, mainly CO_2 (IPCC, 2007a).

The basic physics underlying this global warming, the greenhouse effect, is simple. An increase of gases such as CO_2 makes the atmosphere more opaque at the infrared wavelengths that radiate heat to space. Because Earth's radiation to space arises from the highest opaque layer, added opacity causes heat radiation to space to arise from higher, colder levels, thus reducing heat energy emitted to space. The imbalance between absorbed solar energy and heat emitted to space, causes the planet to warm.

Efforts to assess dangerous climate change have focused on estimating a permissible level of global warming. The Intergovernmental Panel on Climate Change (IPCC, 2001, 2007a) summarized broad-based assessments with a "burning embers" diagram, which indicated that major problems begin with global warming of 2-3°C warming. Sophisticated probabilistic analyses (Schneider and Mastrandrea, 2005) found a median "dangerous" threshold of 2.85°C, with 90% confidence range 1.45-4.65°C. These assessments were relative to global temperature in 2000; add 0.7°C to obtain warming relative to 1880-1920. The conclusion that humanity could tolerate global warming up to a few degrees Celsius meshed with common sense. After all, people readily tolerate much larger regional and seasonal climate variations.

The fallacy of this logic began to emerge in recent years as numerous impacts of global warming became apparent. Summer sea ice cover in the Arctic plummeted in 2007 and 2011 to an area 40 percent less than a few decades earlier with Arctic sea ice thickness declining a factor of four faster than in IPCC climate models (Rampal et al., 2011). The Greenland and Antarctic ice sheets began to shed ice at a rate, now several hundred cubic kilometers per year, which is continuing to accelerate (Velicogna et al. 2009; Rignot et al., 2011). Mountain glaciers are receding rapidly all around the world with effects on seasonal freshwater availability of major rivers (Barnett et al., 2008; Kaser at al., 2010). The hot dry subtropical climate belts have expanded with global warming (Held and Soden, 2006; Seidel and Randel, 2008), probably contributing to observed increases in the area and intensity of wildfires (Westerling et al., 2008). The geographic extent of coral reef ecosystems is decreasing at a rate of 1-2%/year, at least in part due to ocean warming and acidification caused by rising CO_2 (Bruno and Selig, 2007; Hoegh-Guldberg et al., 2007; Veron et al., 2009). Mega-heatwaves, such as those in the Moscow area in 2010 and Texas in 2011, have become more widespread with the increase demonstrably linked to global warming (Rahmstorf and Coumou, 2011).

Considering observed growing climate impacts while global warming is less than 1°C above preindustrial levels, reassessment of the dangerous level of warming is needed. Earth's paleoclimate history provides a valuable tool contributing to that objective.

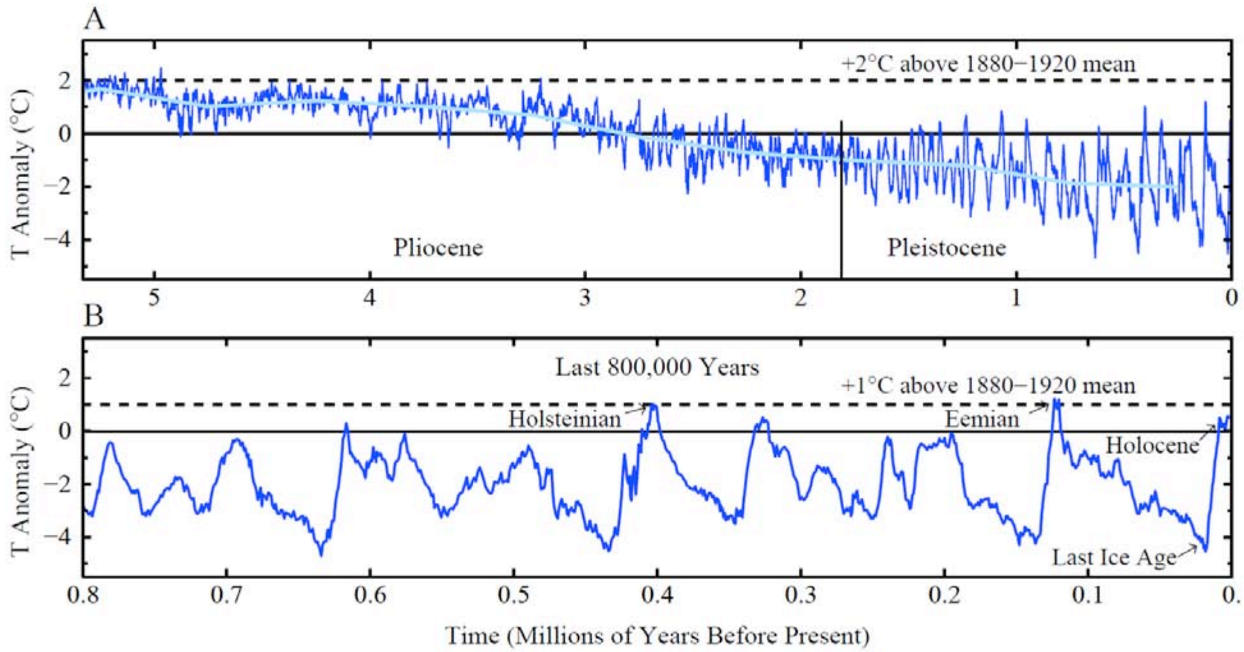

Fig. 2. Global temperature relative to 1880-1920 in (A) past 5 million years and (B) past 800,000 years (Hansen and Sato, 2011).

Paleoclimate Temperature. Global surface temperature in the Pliocene and Pleistocene (Fig. 2) is based on the composition of shells of deep-sea-dwelling microscopic animals preserved in ocean sediments (Zachos et al., 2001; Hansen et al., 2008). Surface temperature change between the Holocene and the last ice age was about 1.5 times larger than deep ocean temperature change, because deep ocean temperature change was limited as it approached the freezing point (Hansen and Sato, 2011). We assume the same surface temperature amplification toward higher temperatures, which may tend to overestimate Pliocene surface temperature (Hansen and Sato, 2011).

The paleoclimate (Fig. 2) and modern (Fig. 1) temperature records are concatenated via the assumption that peak Holocene temperature (prior to the warming of the past century) was +0.5°C relative to the 1880-1920 mean. Estimated uncertainty in this concatenation is ±0.25°C. The fact that Antarctica and Greenland are losing mass at an accelerating rate (Velicogna et al, 2009; Rignot et al., 2011) and sea level is now rising at a rate (+3m/millennium) much higher than during the past several thousand years provides strong evidence that the temperature in the past decade (average +0.75°C) exceeded the prior Holocene maximum.

The climate oscillations evident in Fig. 2 were instigated by very weak forcings, minor perturbations of Earth's orbit and the tilt of its spin axis relative to the orbital plane that alter the seasonal and geographical distribution of sunlight on the planet (REF). The forcings change very slowly, with time scales between 20,000 and 400,000 years, and thus the climate is able to stay in quasi-equilibrium with the forcings. Although the slow insolation changes instigated the climate oscillations in Fig. 2, the mechanisms that caused the climate changes to be so large were two powerful amplifying feedbacks: the planet's surface albedo (its reflectivity, literally its whiteness) and the amount of atmospheric CO_2. As the planet becomes warmer, ice and snow melt, causing the surface to be darker, absorb more sunlight and warm further. As the ocean and soil become warmer they release CO_2 and other greenhouse gases, causing further warming. These amplifying feedbacks were responsible for almost the entire glacial-to-interglacial temperature change (Hansen et al., 2007a; 2008; Köhler et al., 2010; Rohling et al., 2011).

Albedo and CO_2 feedbacks acted as slaves to weak orbital forcings in the natural climate variations in Fig. 2, changing slowly over millennia in. Today, however, CO_2 is under the control of humanity as fossil fuel emissions overwhelm natural changes. CO_2 has thus increased rapidly to a level not seen for at least 3 million years (Pagani et al., 2010). Global warming induced by increasing CO_2 will cause ice to melt and sea level to rise as the global volume of ice moves toward the quasi-equilibrium amount that exists for a given global temperature. As the ice melts and its area decreases the albedo feedback will amplify the global warming.

Paleoclimate data provide a quantitative indication of the eventual ice melt and sea level rise that will accompany a given level of global warming. The Eemian and Hosteinian interglacial periods, also known as marine isotope stages 5e and 11, respectively about 130,000 and 400,000 years ago, were about 1°C warmer than the 1880-1920 mean (Fig. 2B). This was warm enough for sea level to reach mean levels at least 4-6 meters higher than today (Hearty et al., 2007; Rohling et al., 2008; Kopp et al., 2009; Thomson et al., 2011). Global mean temperature 2°C higher than the 1880-1920 mean has not existed since at least the early to mid Pliocene (Fig. 2A), a few million years ago. Sea level at that time was 15-25 meters higher than today (Dowsett et al., 1999).

The paleoclimate record is less useful for estimating how fast ice sheets will respond to global warming, because the human-made climate forcing is practically instantaneous compared with the slowly changing forcings that drove the climate changes in Fig. 2. Paleoclimate records do reveal instances of sea level changes as much as 1-5 meters in a century (REF), indicating that the inherent response time of ice sheets is not as slow time scale of paleoclimate forcings.

However, global observations of on-going climate system changes provide another assessment tool. The rapid global warming of the past three decades (Fig. 1) is already producing measurable effects.

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[Above 3 sections, pages 1-6, have been edited into a style and compactness appropriate for publication. Remaining part is an earlier draft, but the figures have been changed to clarify that emissions reductions required to achieve 350 ppm CO_2 this century, if reductions begin in 2012, are at least 6%/ year. The required rate would have been about 3.5%/year if reductions had started in 2005, and the required rate will be about 15%/year if reductions begin in 2020. The text of the following pages still must be edited into a more compact style, after which the complete edited version of the paper will be placed on arXiv. James Hansen 14 November 2011]

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Earth's Energy Imbalance

Earth's energy balance is a vital measure of the status of Earth's climate. In a period of climate stability, Earth radiates as much energy to space as it absorbs from incident sunlight. Today Earth is out of balance because of increasing atmospheric CO_2. Greenhouse gases such as CO_2 reduce Earth's heat radiation to space, causing a temporary energy imbalance, more energy coming in than going out. This imbalance causes Earth to warm until energy balance is restored.

The immediate planetary energy imbalance due to an increase of CO_2 can be calculated precisely. It does not require a climate model. The radiation physics is rigorously understood. However, the current planetary energy imbalance is complicated by the fact that increasing CO_2 is only one of the factors affecting Earth's energy balance, and Earth has already partly responded to the net climate forcing by warming 0.8°C in the past century.

Consequently, authoritative determination of the state of the climate system requires measuring the planet's current energy imbalance. This is a technical challenge, because the magnitude of the imbalance is expected to be only about 1 W/m^2 or less, so measurements must have an accuracy that approaches 0.1 W/m^2. The most promising approach to achieve this accuracy is to measure ongoing changes of the heat content of the ocean, atmosphere, land, and ice on the planet.

Observed planetary energy imbalance. The vast global ocean is the primary reservoir for changes of Earth's heat content. Because of the importance of this measurement, nations of the world launched a cooperative Argo float program, which has distributed more than 3000 floats around the world ocean (Roemmich and Gilson, 2009). Each float repeatedly sends an instrument package to a depth of two kilometers and back. Data are communicated via satellite to shore-based facilities.

The Argo program did not attain planned distribution of floats until late 2007, but coverage reached 90% by 2005, allowing good accuracy provided that systematic measurement errors are kept sufficiently small. Prior experience showed how difficult it is to eliminate all measurement biases, but the exposure of the difficulties over the past decade leads to expectation that the data for the 6-year period 2005-2010 are the most precise achieved so far.

Heat gain during 2005-2010 in the upper 2000 m of ocean sampled by Argo floats was 0.42 W/m^2 averaged over Earth's surface. Smaller contributions to planetary energy imbalance were provided by heat gain in the deeper ocean (+0.10 W/m^2), with the deep ocean estimates based on more spotty measurements over a decadal period, energy used in net melting of ice (+0.05 W/m^2), with loss of Arctic sea ice, the Greenland and Antarctic ice sheets, mountain glaciers and small ice caps all contributing to net heat uptake, and energy taken up by warming continents (+0.02 W/m^2). Data sources for these estimates and uncertainties are provided elsewhere (Hansen et al., 2011). The resulting net planetary energy imbalance for the six years 2005-2010 is +0.59 W/m^2 with estimated uncertainty 0.15 W/m^2.

The positive energy imbalance in 2005-2010 is particularly important, because that period has the lowest level of solar irradiance since accurate measurements of the sun began in the late 1970s (Frohlich and Lean, 1998). Solar variability is often hypothesized to be the one natural climate forcing with the potential to compete with human-made climate forcings. However, the large energy gain by Earth at the time of minimum solar irradiance confirms that the reduction of solar heating is overwhelmed by the warming effect of other climate forcings.

This result is not surprising, because the climate forcing by human-made greenhouse gases is known to be much larger than the forcing due to measured solar variability. The greenhouse gas forcing has been only partly expended in causing the observed 0.8°C global warming of the past century. The measured planetary energy imbalance is the net climate forcing that continues to act on our planet.

Earth's energy imbalance averaged over the 11-year cycle of solar variability is likely to be larger than the measured +0.59 W/m^2 at solar minimum. Hansen et al. (2011) suggest that the mean imbalance averaged over the solar cycle may be closer to +0.75 W/m^2, with uncertainty ±0.25 W/m^2. Precise quantification of Earth's energy imbalance will help us assess how much additional global warming is already 'in the pipeline'.

Implications for atmospheric CO_2 target. Accurate knowledge of Earth's energy imbalance will allow specification of how much CO_2 must be reduced to restore planetary energy balance and stabilize climate, if other factors remain unchanged. Earth's measured energy imbalance accounts for all natural and human-made climate forcings, including changes of the planet's surface reflectivity due to human activities and changes of atmospheric aerosols.

If Earth's mean energy imbalance is +0.5 W/m^2, CO_2 must be reduced from the current level of 390 ppm to about 360 ppm to increase Earth's heat radiation to space by 0.5 W/m^2 and restore energy balance, assuming that other forcings remain unchanged. If Earth's energy imbalance is 0.75 W/m^2, CO_2 must be reduced to about 345 ppm to restore energy balance.

Earth's measured energy imbalance thus affirms the conclusion that a good initial target level for atmospheric CO_2 to stabilize climate is "<350 ppm" (Hansen et al., 2008). The CO_2 target level must be refined as climate stability is approached. However, given the difficulty of reversing the growth of atmospheric CO_2, it is apparent that more precise knowledge of the ultimate target for CO_2 should be available by the time CO_2 has been restored to a concentration approaching 350 ppm.

Specification now of a CO_2 target more precise than "<350 ppm" seems inadvisable, as well as unnecessary, because of uncertainty about other human-made climate forcings such as changes of surface reflectivity, methane, other trace gases, reflecting aerosols, and black soot. These forcings are smaller than that by CO_2, but not negligible.

Future reductions of particulate air pollution may exacerbate global warming by reducing the cooling effect (negative climate forcing) of reflective aerosols. However, a concerted effort to reduce methane, tropospheric ozone, other trace gases and black soot may be sufficient to counteract the warming effect of a decline in reflective aerosols (Hansen et al., 2000). Our calculations of future global temperature below assume that reductions of these non-CO_2 forcings will be sufficient to offset changed forcing by reflective aerosols. To the degree that this goal is not achieved, future warming could exceed calculated expectations.

The important point is that CO_2 is the dominant climate forcing agent and it will be even more so in the future. The CO_2 injected into the climate system by burning fossil fuels will continue to affect our climate for millennia. We cannot burn all of the fossil fuels without producing a different planet, with changes occurring with a rapidity that will make Earth far less hospitable for young people, future generations, and most other species.

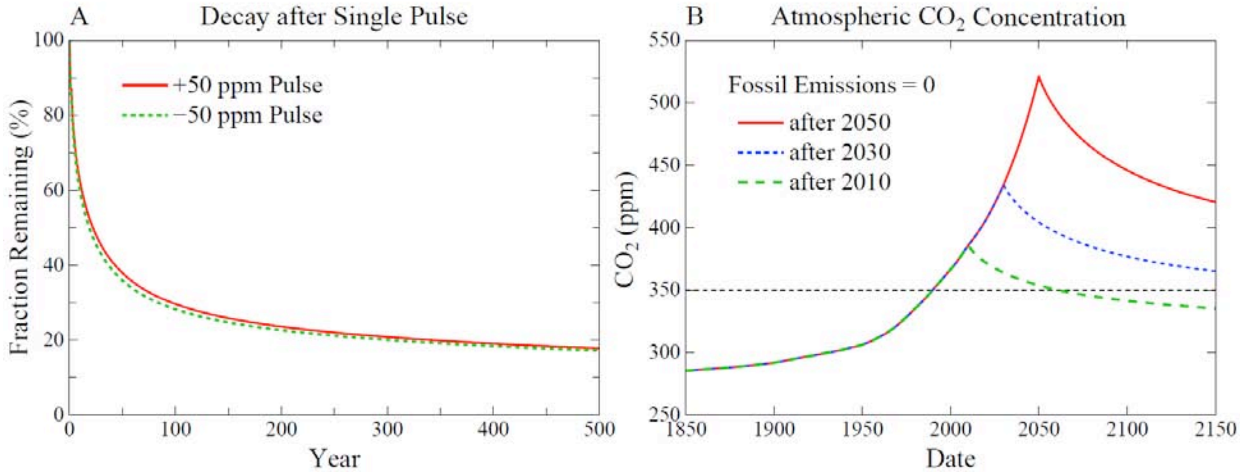

Figure 3. (A) Decay of instantaneous (pulse) injection and extraction of atmospheric CO_2, (B) CO_2 amount if fossil fuel emissions are suddenly terminated at the end of 2010, 2030, 2050.

Carbon Cycle and Atmospheric CO_2

The 'carbon cycle' that defines the fate of fossil fuel carbon injected into the climate system is well understood (Archer, 2005; IPCC, 2007a). This knowledge allows accurate estimation of the amount of fossil fuels that can be burned consistent with restoring Earth's energy balance this century. Atmospheric CO_2 is already at about 390 ppm. However, it is still feasible to get CO_2 back to a level near 350 ppm this century via a combination of rapid reduction of fossil fuel emissions and aggressive measures to increase CO_2 uptake by the soils and biosphere.

Carbon cycle simulations. CO_2 injected into the air by burning fossil fuels distributes itself over time among the surface carbon reservoirs: the atmosphere, ocean, soil, and biosphere. Here we use the well-tested Bern carbon cycle model to account for this redistribution and illustrate how rapidly atmospheric CO_2 could potentially decrease. Specifically, we use the dynamic-sink pulse-response function representation of the Bern model (Joos et al., 1996), as described by Kharecha and Hansen (2008) and Hansen et al. (2008).

A pulse of CO_2 injected into the air decays by about half in 25 years (Fig. 3). However, nearly one-fifth of the CO_2 is still in the atmosphere after 500 years. Eventually, over millennia, weathering of rocks will deposit this excess CO_2 on the ocean floor as carbonate sediments.

A negative CO_2 pulse decays at about the same rate as a positive pulse (Fig. 3a), which is an important fact for policy considerations. If it is decided in the future that CO_2 must be sucked from the air and removed from the carbon cycle (e.g., by making carbonate bricks or storing the CO_2 in underground reservoirs), the magnitude of the CO_2 reduction will decline as the negative CO_2 increment becomes spread among the carbon reservoirs.

It is instructive to examine how fast atmospheric CO_2 would decline if fossil fuel use were instantly terminated. If emissions were halted in 2011, CO_2 would decline to 350 ppm at mid-century (Fig. 3b). With a 20 year delay in halting emissions, CO_2 returns to 350 ppm at about 2250. With a 40 year delay, CO_2 does not return to 350 ppm until after year 3000. These results suggest how difficult it will be to get back to 350 ppm CO_2 if fossil fuel emissions continue at a high level for even a few decades.

Deforestation and reforestation effects. The above results do not necessarily imply that it is implausible for atmospheric CO_2 to return to the 350 ppm level this century. We must also account for one other major factor in the carbon cycle: the effects of deforestation/reforestation.

Fossil fuel emissions account for about 80 percent of the increase of atmospheric CO_2 from 275 ppm in the preindustrial atmosphere to 390 ppm today. The other 20 percent is from net deforestation, where net deforestation accounts for forest regrowth. Net deforestation over the industrial era is estimated to be about 100 GtC (gigatons of carbon), with uncertainty about 50 percent (Stocker et al., 2011) Net deforestation of 100 GtC and historical fossil fuel use yield good agreement with historical growth of atmospheric CO_2 based on simulations with the Bern carbon cycle model (Figure S16 of Hansen et al., 2008).

Reforestation and improved forestry and agricultural practices potentially could help extract CO_2 from the atmosphere. Complete restoration of deforested areas is unrealistic, yet a total 100 GtC drawdown of CO_2 is conceivable for the following reasons: (1) the current human-enhanced atmospheric CO_2 level increases carbon uptake by vegetation and soils, (2) improved agricultural practices can convert agriculture from being a large CO_2 source into a carbon sink (Hillel and Rosenzweig, 2011), (3) biomass-burning power plants with CO_2 capture and storage could contribute to CO_2 drawdown.

Use of bioenergy to help draw down atmospheric CO_2 should employ feedstocks only from residues, wastes, and dedicated energy crops that do not compete with food crops, unlike most current-generation bioenergy sources, thus avoiding loss of natural ecosystems and cropland (Tilman et al., 2006; Fargione et al., 2008; Searchinger et al., 2008). Reforestation must compete with other land use, especially expansion of agriculture to feed a growing world population. Decreased use of animal products would reduce demand for agricultural land, as more than half of all crops are currently fed to livestock (Stehfest et al., 2009; UNEP, 2010).

Forest and soil storage of 100 GtC is a major task, yet it is possible and, as we will show, it is probably essential if atmospheric CO_2 is to be returned close to the 350 ppm level. This carbon storage has other major benefits. Present agricultural practices, based on plowing and chemical fertilizers, are dependent on fossil fuels and contribute to loss of carbon from soil via land degradation, but successful reforestation has been demonstrated in places (Lamb, 2011). World agriculture could sequester 0.4-1.2 GtC per year by adopting minimum tillage and biological nutrient recycling (Smith et al., 2008; Smith, 2011). That strategy can also increase water conservation in soils, build agricultural resilience to climate change, and increase productivity especially in smallholder rain-fed agriculture, thereby reducing expansion of agriculture into forested ecosystems (Rockstrom et al., 2009; Smith et al., 2010).

Consequently, we assume a 100 GtC drawdown (biospheric C uptake) in our reforestation scenarios, using a sinusoidal drawdown over the period 2031-2080. Alternative timings of this drawdown would have no qualitative effect on our conclusions about the potential for achieving a given CO_2 level such as 350 ppm.

CO_2 emission reduction scenarios. Reforestation of 100 GtC results in atmospheric CO_2 declining to 350 ppm by the end of this century, if fossil fuel emissions decline at least 6% per year beginning in 2013 (Fig. 4a). The effect of continued fossil fuel emissions at a business-as-usual (BAU) rate (2%/year) is shown in Fig. 4b.

Delaying initiation of emission cuts until 2020 causes CO_2 to remain in the dangerous zone for climate (i.e., above 350 ppm) until 2300. If emissions reduction is delayed until 2030 or later, atmospheric CO_2 does not return to the 350 ppm level even by 2500. We conclude that a major reforestation program would permit the possibility of returning CO_2 to the 350 ppm level within this century, but only if rapid fossil fuel emission reductions begin promptly.

Phasing out deforestation by 2020, and moving 100 GtC reforestation to 2020-2070, would allow an even more rapid return to the 350 ppm target. Such adjustments have little effect on the

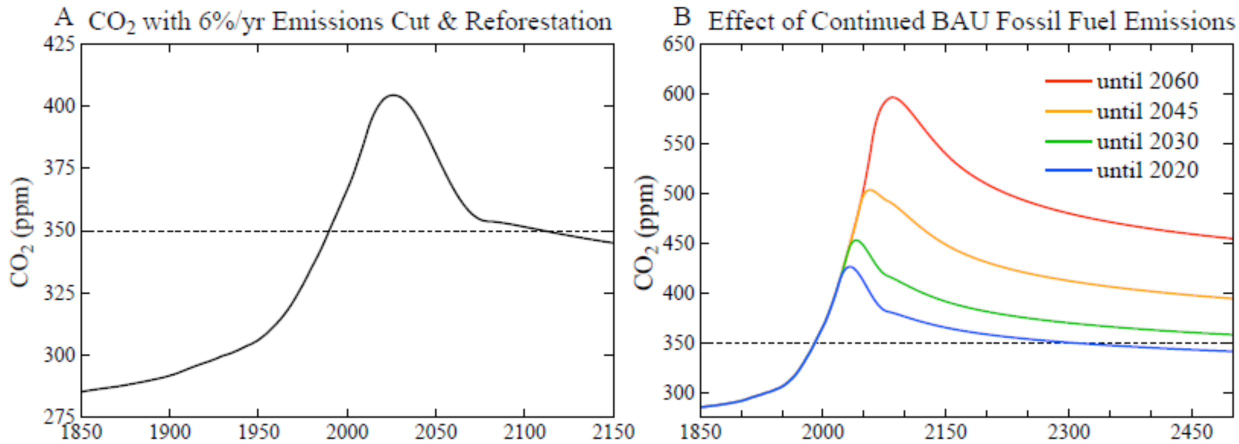

Figure 4. (a) Atmospheric CO_2 if fossil fuel emissions are cut 6%/year beginning in 2013 and 100 GtC reforestation drawdown occurs in 2031-2080, (b) effect of delaying onset of emissions reduction.

expected global temperature maximum though, calculated in the next section. The dominant factor, by far, is the date at which fossil fuel emission phase-out begins.

Geo-engineering atmospheric CO_2. Perceived political difficulties of phasing out fossil fuel emissions have caused a surge of interest in possible 'geo-engineering' designed to minimize human-made climate change (Royal Society, 2009). Such efforts must remove atmospheric CO_2, if they are to avoid direct CO_2 effects such as ocean acidification.

At present there are no technologies capable of large-scale air capture of CO_2. Keith et al. (2006) suggest that, with strong research and development support and industrial scale pilot projects sustained over decades, costs as low as ~$500/tC may be achievable. An assessment by the American Physical Society (http://www.aps.org/about/pressreleases/dac11.cfm) argues that the cost would be much greater ($600/t$CO_2$ or $2200/tC), making their global construction to deal with a climate emergency implausible.

The cost of removing 50 ppm of CO_2, at $500/tC, is ~$50 trillion (1 ppm CO_2 is ~2.12 GtC), but more than $200 trillion for the price estimate of the American Physical Society study. Moreover, the resulting atmospheric CO_2 reduction is only ~15 ppm after 100 years, because most of the extraction leaks into other surface carbon reservoirs (Fig. 3a). The estimated cost of maintaining a 50 ppm reduction on the century time scale is thus ~$150-600 trillion.

Below we discuss economic and social benefits of rapidly phasing over to clean energies and increased energy efficiency, as opposed to continued and expanded extraction of fossil fuels. At this point, we simply note that the present generation will be passing the CO_2 clean-up costs on to today's young people and future generations, if fossil fuel emissions are not phased out.

Future Global Temperature Change

Future global temperature change depends mainly on atmospheric CO_2 amount. CO_2 accounts for more than 80 percent of the growth of greenhouse gas climate forcing in the past 15 years (Reference). Natural climate forcings, such as changes of solar irradiance and volcanic aerosols, contribute to global temperature variations, but their effect on the long-term global temperature trend is small compared with the effect of CO_2.

Global temperature change for a given CO_2 scenario can be simulated using a climate response function that accurately replicates results from sophisticated global climate models. We use the 'intermediate' response function (Fig. 9 of Hansen et al., 2011), which replicates well observed ocean heat uptake and observed global temperature change of the past century.

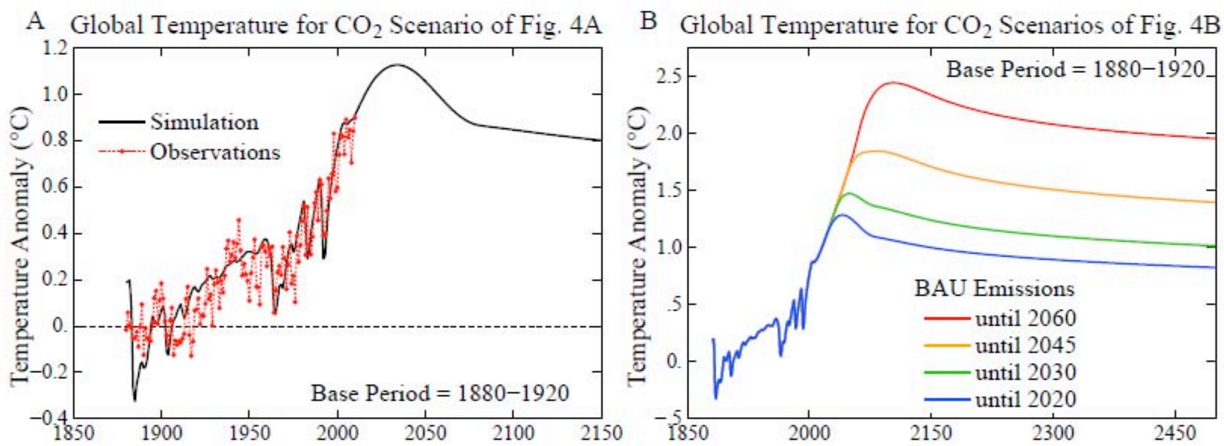

Figure 5. Simulated global temperature relative to 1880-1920 mrsn for CO_2 scenarios of Fig. 4.

Importance of slow climate feedbacks. One caveat must be stressed. These calculations, as with most global climate models, incorporate only the effect of the so-called 'fast feedbacks' in the climate system, such as water vapor, clouds, aerosols, and sea ice. Slow feedbacks, such as ice sheet disintegration and climate-induced changes of greenhouse gases, as may occur with the melting of tundra and warming of continental shelves, are not included.

Exclusion of slow feedbacks is appropriate for the past century, because the ice sheets were stable and our climate simulations employ observed greenhouse gas amounts. Observed greenhouse gas amounts include any changes caused by slow feedbacks. Exclusion of slow feedbacks in the 21st century is a dubious assumption, used in our computations here only because the rate at which slow feedbacks come into play is poorly understood. However, we must bear in mind the potential for slow feedbacks to fundamentally alter the nature of future climate change. Specifically, the principal slow feedbacks have an amplifying effect and they could create a situation with continuing climate change that is largely out of humanity's control.

Slow feedbacks help to crystallize the need to keep maximum warming from significantly exceeding 1°C. With current global warming evidence of slow feedbacks is beginning to appear, e.g., increasing loss of ice mass from Greenland and Antarctica (Velicogna, 2009; Rignot et al., 2011) and methane release by melting tundra (Walter et al., 2006) and warming of sea-bed gas hydrates (Westbrook et al., 2009). The fact that observed effects are small so far suggests that these feedbacks may not be a major factor if maximum global warming reaches only ~1°C and then recedes.

In contrast, if BAU CO_2 emissions continue for many decades there is little doubt that these slow feedbacks will come into play in major ways. CO_2 injected into the air stays in the surface carbon reservoirs for millennia, so the slow feedbacks will occur if CO_2 amount is elevated to a high level. It is only a question of how fast the slow feedbacks would occur, and thus which generations would suffer the greatest consequences.

There humanity faces a dichotomy. Either we achieve a scenario with declining CO_2 emissions, thus preserving a planetary climate resembling the Holocene or we pass tipping points that assure transition to a very different planet with foreseen and unforeseen consequences.

Dangerous level of warming. What level of global warming would necessarily push Earth past such tipping points? We cannot be precise, due to poor understanding of slow feedbacks. But consider the case with BAU emissions until 2030 (Fig. 5b). Even though CO_2 emissions are phased out rapidly (5%/year reductions) after 2030 and 100 GtC reforestation occurs in 2031-2080, the global temperature rise reaches 1.5°C and stays above 1°C until after 2400. It is highly unlikely that the ice sheets would be stable at their present size with such long-lasting warmth. If BAU continues only until 2020, the temperature rise exceeds 1°C for about 100 years.

The scenario with 6%/year reduction of CO_2 emissions beginning in 2013 (Fig. 5a) yields a maximum global temperature just exceeding 1°C, remaining above that level for just a few decades. This scenario provides the prospect that humanity and other life on the planet still have a chance of residing in a world similar to the one in which civilization developed.

Precise consequences of continuing BAU emissions for several decades are difficult to define, because Earth has never experienced such a large rapid increase of climate forcings as would occur with burning of most fossil fuels this century. The closest known analogy in Earth's history is the PETM (Paleocene-Eocene Thermal Maximum) in which rapid global warming of at least 5°C occurred (Zachos et al., 2001). The PETM warming spike occurred in conjunction with injection of 3000-5000 GtC of carbon into the surface climate system during two 1-2 thousand year intervals separated by several thousand years (Zeebe et al., 2009). This carbon is presumed to have originated from melting of methane hydrates, because of the absence of other known sources of that magnitude. PETM occurred during a 10-million year period of slow global warming, and thus methane release may have been a feedback that magnified warming that was already occurring.

The PETM witnessed extinction of about half of the small shelled deep ocean animals that serve as a biological indicator for ocean life in general, but, unlike several other large warming events in Earth's history, there was little extinction of land plants and animals (REF). However, human-made warming is occurring 10-100 times faster than during the PETM, pushing Earth into uncharted climate change territory with climate zones shifting much faster than species have ever endured. The ability of most life on Earth to survive such a climate shock is highly dubious.

Likely Impacts of Global Warming

Despite the absence of a good paleoclimate analog, we can use a variety of sources to gain insight about likely effects of human-made warming. Paleoclimate data provide an indication of likely long-term responses to changed boundary conditions. Global observations of ongoing climate change help to reveal the rate at which changes may occur. Climate models allow us to simulate the global response to alternative climate forcings. But we must bear in mind that some important processes, such as ice sheet disintegration and species extermination, are difficult to simulate and have the potential to be highly non-linear. That means changes can be slow until a tipping point is reached (Lenton et al., 2008) and more rapid change occurs.

Sea level. The most recent prior interglacial period, the Eemian, was at most about 1°C warmer than the Holocene (Fig. 2). Sea level reached heights several meters above today's level with instances of sea level change by 1-2 meters per century (Rohling et al., 2008; Muhs et al., 2011). Geologic shoreline evidence has been interpreted as indicating a rapid sea level rise to a peak 6-9 meters above present late in the Eemian followed by a precipitous sea level fall (Hearty and Neumann, 2001; Hearty et al., 2007), although there remains debate within the research community about this specific history. The important point is that the high Eemian sea level excursions imply rapid partial melting of Antarctic and/or Greenland ice when the world was little warmer than today. During the Pliocene, when Earth may have been only 1-2°C warmer than the Holocene (Figure 2), sea level was probably 15-25 meters higher than today (Dowsett et al., 1999, 2009; Naish et al., 2009).

Expected human-caused sea level rise is controversial because predictions (IPCC, 2001, 2007) focus on sea level rise by a specific date, 2100. Recent estimates of sea level rise by 2100 are around 1 m (Vermeer and Rahmstorf, 2009; Grinsted et al., 2010). Ice-dynamics studies estimate that rates of sea-level rise of 0.8 to 2 m per century are feasible (Pfeffer et al., 2008) and Antarctica alone could contribute up to 1.5 m per century (Turner et al., 2009). Hansen (2005, 2007) has argued that BAU CO_2 emissions produce a climate forcing so much larger than any experienced in prior interglacial periods that a non-linear ice sheet response with multi-meter sea level rise could occur this century.

Accurate measurements of ice sheet mass loss may provide the best means to detect nonlinear ice sheet loss. The GRACE satellite, measuring Earth's gravitational field since 2003, reveals that the Greenland ice sheet is losing mass at an accelerating rate, now more than 200 cubic kilometers per year, and Antarctica is losing more than 100 cubic kilometers per year (Sorensen and Forsberg, 2010; Rignot et al., 2011). However, the present rate of sea level rise, 3 cm per decade, is moderate, and the ice sheet mass balance record is too short to determine whether we have entered a period of continually accelerating ice loss.

Satellite observations of Greenland show that the surface area with summer melting has increased over the period of record, which extends back to the late 1970s (Steffen et al., 2004; Tedesco et al., 2011). Yet the destabilizing mechanism of greatest concern is melting of ice shelves, tongues of ice that extend from the ice sheets into the oceans and buttress the ice sheets, limiting the rate of discharge of ice to the ocean. Ocean warming is causing shrinkage of ice shelves around Greenland and Antarctica (Rignot and Jacobs, 2002).

Loss of ice shelves can open a pathway to the ocean for portions of ice sheets that rest on bedrock below sea level. Most of the West Antarctic ice sheet, which alone could raise sea level by 3-5 meters, rests on bedrock below sea level, making the ice sheet highly vulnerable to rapid change. However, parts of the larger East Antarctic ice sheet are also vulnerable. Indeed, satellite gravity and radar altimetry reveal that the Totten Glacier of East Antarctica, fronting a large ice mass grounded below sea level, is already beginning to lose mass (Rignot et al., 2008)

The important point is that uncertainties about sea level rise mainly concern the timing of large sea level rise if BAU emissions continue, not whether it will occur. If all or most fossil fuels are burned, the carbon will be in the climate system for many centuries, in which case multi-meter sea level rise is practically certain (e.g., Rohling et al., 2009). Such a sea level rise would create hundreds of millions of global warming refugees from highly-populated low-lying areas, who must migrate from the coastline, throwing existing global demographics into chaos.

Shifting climate zones. Theory and climate models indicate that subtropical regions expand poleward with global warming (Held and Soden, 2006; IPCC, 2007). Observations already reveal a 4-degree latitude average poleward expansion of the subtropics (Seidel and Randel, 2006), yielding increased aridity in the southern United States (Barnett et al., 2008; Levi, 2008), the Mediterranean region, and Australia. Increased aridity and temperatures contribute to increased forest fires that burn hotter and are more destructive (Westerling et al., 2006).

Despite large year-to-year variability of seasonal temperature, decadal averages reveal that isotherms (lines of a given average temperature) have been moving poleward at a rate of about 100 km per decade during the past three decades (Hansen et al., 2006). This rapid shifting of climatic zones far exceeds natural rates of change. The direction of movement (poleward) has been monotonic since about 1975. Wild species have responded to this climatic shift, with at least 52 percent of species having shifted their ranges poleward (and upward) by as much as 600 km in terrestrial systems and 1000 km in marine systems (Parmesan and Yohe, 2003; Hoegh-Guldberg and Bruno, 2010). This trend will continue as long as the planet is as far out of energy balance as at present, a conclusion based on comparison of the observed trend with interdecadal variability in climate simulations (Hansen et al., 2007).

Humans may be to adapt to shifting of climate zones better than many other species. However, political borders can interfere with migration, and indigenous ways of life have already been adversely affected (IPCC, 2007b). Impacts are apparent in the Arctic, with melting tundra, reduced sea ice, and increased shoreline erosion. Effects of shifting climate zones may also be important for indigenous Americans who possess specific designated land areas, as well as other cultures with long-standing traditions in South America, Africa, Asia and Australia.

Loss of Species. The explosive rise of human population globally is having a profound influence on the well being of all other species. As recently as two decades ago biologists were more concerned with effects on biodiversity other than climate change, such as land use changes, nitrogen fertilization, and the direct effects of increased atmospheric CO_2 on plant ecophysiology (Parmesan, 2006). However, easily discernible impacts on animals, plants, and insects of the nearly monotonic global warming during the past three decades (Fig. 1) have sharply altered perceptions of the greatest threats.

A dramatic awakening was provided by sudden widespread decline of frogs, with extinction of entire mountain-restricted species attributed to global warming (Pounds et al., 1999, 2006). Although there are somewhat different interpretations of the detailed processes involved in global amphibian declines and extinctions (Alford et al., 2007; Fagotti and Pascolini, 2007), there is agreement that global warming is a main contributor to a global amphibian crisis: "The losses portend a planetary-scale mass extinction in the making. Unless humanity takes immediate action to stabilize the climate, while also fighting biodiversity's other threats, a multitude of species is likely to vanish" (Pounds et al., 2007).

Mountain-restricted species are particularly vulnerable to global warming. As isotherms move up the mountainside, so does the climate zone in which a given species can survive. If global warming continues unabated, many mountain-dwelling species will be driven to extinction as these species literally run out of mountain habitat.

Polar-restricted species face similar problems. There are documented reductions in the population and health of Arctic species living in the southern parts of the Arctic and Antarctic species in the more northern parts of the Antarctic. A critical factor for survival of some Arctic species will be retention of all-year sea ice. Continued BAU fossil fuel use will result in loss of all Arctic summer sea ice within the next several decades. In contrast, the scenario in Fig.5a, with global warming peaking just over 1°C and then declining slowly, should allow some summer sea ice to survive and then gradually increase to levels representative of recent decades.

The threat to species survival is not limited to mountain and polar species. Plant and animal distributions are a reflection of the regional climates to which they are adapted. Although species attempt to migrate in response to climate change, their paths may be blocked by human-constructed obstacles or natural barriers such as coast lines. As the shift of climate zones becomes comparable to the range of some species, the less mobile species will be driven to extinction. Because of extensive species interdependencies, this can lead to mass extinctions.

IPCC Working Group II (IPCC, 2007b) reviews studies relevant to estimating eventual extinctions as a function of global warming. If global warming relative to the pre-industrial level exceeds 1.6°C, they estimate that 9-31 percent of species will be committed to extinction. With global warming of 2.9°C, an estimated 21-52 percent of species will be committed to extinction.

Mass extinctions have occurred in conjunction with rapid climate change during Earth's long history, and new species evolved over hundreds of thousands and millions of years. But such time scales are almost beyond human comprehension. If we drive many species to extinction we will leave a more desolate planet for our children, grandchildren, and as many generations as we can imagine.

Coral reef ecosystems. Coral reefs, often described as the rainforests of the ocean, are the most biologically diverse marine ecosystem. An estimated 1-9 million species, most not yet described (Reaka-Kudla, 1997), populate coral reef ecosystems generating crucial ecosystem services for several hundred million people in tropical coastal areas. These ecosystems are highly vulnerable to the combined effects of ocean acidification and warming.

Acidification arises as the ocean absorbs CO_2, producing carbonic acid. Geochemical records show that ocean pH is already outside its range of the past several million years (Raven et al., 2005; Pelejero et al., 2010). Warming causes coral bleaching, as overheated coral expel symbiotic algae and become vulnerable to disease and mortality (Hoegh-Guldberg, 1999). Coral bleaching and slowing of coral calcification already are causing mass mortalities, increased coral disease, and reduced reef carbonate accretion, thus disrupting coral reef ecosystem health (Hoegh-Guldberg et al., 2007; De'Ath et al., 2009).

Local human-made stresses add to the global warming and acidification effects, together driving a rapid contraction, 1-2% per year, in the extent of coral reefs (Bruno and Selig, 2007). Loss of the three-dimensional framework that typifies coral reefs has consequences for the millions of species that depend on the reefs for their existence. Loss of these frameworks also has consequences for the important roles that coral reefs play in supporting fisheries and protecting coastlines from wave stress. Consequences of lost coral reefs can be economically devastating for many nations, especially in combination with other impacts such as sea level rise.

The situation with coral reefs has been aptly summarized (Schuttenberg and Hoegh-Guldberg, 2007): "Although the current greenhouse trajectory is disastrous for coral reefs and the millions of people who depend on them for survival, we should not be lulled into accepting a world without corals. Only by imagining a world with corals will we build the resolve to solve the challenges ahead. We must avoid the 'game over' syndrome and marshal the financial, political, and technical resources to stabilize the climate and implement effective reef management with unprecedented urgency."

Hydrologic extremes and storms. Extremes of the hydrologic cycle are intensified as Earth becomes warmer. A warmer atmosphere holds more moisture, so heavy rains become more intense and increase flooding. Higher temperatures, on the other hand, cause an intensification of droughts, as does expansion of the subtropics with global warming.

The IPCC (2007) report confirms existence of expected trends, e.g., precipitation has generally increased over land poleward of the subtropics and decreased at lower latitudes. Tropospheric water vapor has increased. Unusually heavy precipitation events have increased substantially across Europe, Australia, Noarth America and Southeast Asia (REF). Droughts are more common, especially in the tropics and subtropics (REF).

Mountain glaciers. Glaciers are in near-global retreat (IPCC, 2007). After a one-time added flush of fresh water, glacier demise will frequently yield summer and autumn drying of rivers originating in the Himalayas, Andes, and Rocky Mountains that now supply water to hundreds of millions of people (Barnett et al., 2008). Present glacier retreat and global warming in the pipeline indicate that 390 ppm of CO_2 is already a threat for future fresh water security (REF).

Human health. Children are especially vulnerable to the health impacts of climate change. Principal effects are summarized in Table 1 under the headings: (1) heat waves, (2) asthma and allergies, (3) spread of infectious disease, (4) pests and invading species affecting forests, crops and marine life, (5) winter weather anomalies, (6) drought, (7) food insecurity. Climate change poses a threat to health through many pathways, especially by placing additional stress on the availability of food, clean air, clean water, and potentially by expanding the burden of disease from vector-borne diseases (Bernstein and Myers, 2011).

World health experts have concluded with "very high confidence" that climate change already contributes to the global burden of disease and premature death (IPCC, 2007b). Effects so far are small, but they are projected to progressively increase in all countries and regions. IPCC (2007b) describes evidence that climate change has already altered the distribution of some infectious disease vectors, altered the seasonal distribution of some allergenic pollen species, and increased heat-related deaths.

If BAU CO_2 emissions continue and global warming increases IPCC (2007b) projects the following trends, where we include only those that are assigned either high confidence or very high confidence: (1) increased malnutrition and consequent disorders, including those related to child growth and development, (2) increased death, disease and injuries from heat waves, floods, storms, fires and droughts, (3) increased cardio-respiratory morbidity and mortality associated with ground-level ozone, (4) some benefits to health, including fewer deaths from cold, although it is expected that these would be outweighed by the negative effects.

Table 1. Climate Change Impacts on Human Health	
Heat waves.	Heat waves are not only increasing in frequency, intensity and duration, but their nature is changing. Warmer nighttime temps [double the increase of average temperature since 1970 (Karl et al., 1993)] and higher humidity (7% more for each 1ºC warming) make heat-waves all the more lethal.
Asthma and allergies.	Asthma prevalence has more than doubled in the U.S. since 1980, with several of the exacerbating factors stemming from fossil fuel burning. Increased CO_2 and warming boost pollen production from fast growing trees in the spring and ragweed in the fall (allergenic proteins also increase). Particulates help deliver pollen and mold spores deep into the lung sacs. Ground-level ozone, which increases in heat-waves, primes the allergic response. Climate change has extended the allergy and asthma season two-four weeks in the Northern Hemisphere (depending on latitude) since 1970. Increased CO_2 stimulates growth of poison ivy and a chemical in it (uruschiol) that causes contact dermatitis.
Spread of infectious disease.	The spread of infectious diseases is influenced by climate change in two ways: warming expands geographic and temporal conditions conducive to transmission of vector-borne diseases (VBDs), while floods can leave "clusters" of mosquito-, water – and rodent-borne diseases (and spread toxins). The warming atmosphere, holding more water vapor, has increased rainfall intensity in the U.S. since 1970 -- 7% overall, 14% for 2"/day rain, 20% for 4"/day, 27% for 6"/day (Groisman et al., 2005), with many implications for health, crops and nutrition. Tick-borne Lyme disease (LD) is the most important VBD in the U.S. LD reports rose 8-fold in New Hampshire in the past decade and 10-fold in Maine (now in all of its 16 counties). Vector ranges are expanding. Biological responses of vectors (and plants) to warming have generally been underestimated, and may be leading indicators of warming due to the disproportionate increase of winter minimum and high latitude temperatures.
Pests and invading species affecting forests, crops and marine ecosystems.	Pests and invading species that affect forests, crops and marine ecosystems are favored in a warming world. Bark beetles are overwintering (absent sustained killing frosts) and expanding their range, and getting in more generations, while droughts in the West dry the resin that drowns the beetles as they try to drive through the bark. (Warming emboldens the pests while extremes weaken the hosts.) Forest health is also threatened in the Northeast U.S. (Asian Long-horned beetle and wooly adelgid of hemlock trees), setting the stage for increased wildfires with injury, death and air pollution, loss of carbon stores, and damage to oxygen and water supplies. In sum, forest pests threaten basic life support systems that underlie human health. Crop pests and diseases are also encouraged by warming and extremes. Warming increases their potential range, while floods foster fungal growth and droughts favor whiteflies, aphids and locust. Higher CO_2 also stimulates growth of agricultural weeds. More pesticides, herbicides and fungicides (where available) pose other threats to human health. Crop pests take up to 40% of yield annually, totaling ~$300 billion in losses (Pimentel). Marine diseases (e.g., coral bleaching and disease, loss of key species such as sea urchins, impacts on aquaculture species), harmful algal blooms (from excess nutrients, loss of filtering wetlands, warmer seas and extreme weather events that trigger HABs by flushing nutrients into estuaries and coastal waters), plus the over 350 "dead zones" globally affect fisheries, thus nutrition and health. Interaction between climate change and local factors such as nutrient pollution is driving an increasing number of dead zones (Diaz and Rosenberg, 2008).
Winter weather anomalies.	Increasing winter weather anomalies is a trend to be monitored. More winter precipitation is falling as rain rather than snow in the Northern Hemisphere, increasing the chances for ice storms, while greater atmospheric moisture increases the chances of heavy snowfalls. Both affect ambulatory health (orthopedics), motor vehicle accidents, cardiac disease and power outages with accompanying health effects.
Drought.	Droughts are increasing in frequency, intensity, duration, and geographic extent. Drought and water stress are major killers in developing nations, bringing disease outbreaks including water-borne cholera and mosquito-borne dengue fever (mosquitoes breed in stored water containers). Drought and higher CO_2 increase the cyanide content of cassava, a staple food in Africa, leading to neurological disabilities and death.
Food insecurity.	Food insecurity is a major problem worldwide. Demand for meat, fuel prices, displacement of food crops with biofuel crops all contribute. Extreme weather events today are an acute driver. Russia's extensive 2010 summer heat-wave (several standard deviations above the norm, killing over 50,000 people) reduced wheat production ~40%; unusually extensive worldwide floods and droughts in 2010 caused grain shortages and raised prices in many nations. Food riots occurred in Uganda and Burkina Faso; resulting desperation from food and fuel price hikes probably contributed to uprisings in North Africa and the Middle East. Food shortages and price hikes contribute to malnutrition that underlies much of poor health and vulnerability to infectious diseases. Food insecurity also leads to political instability, conflict and war.

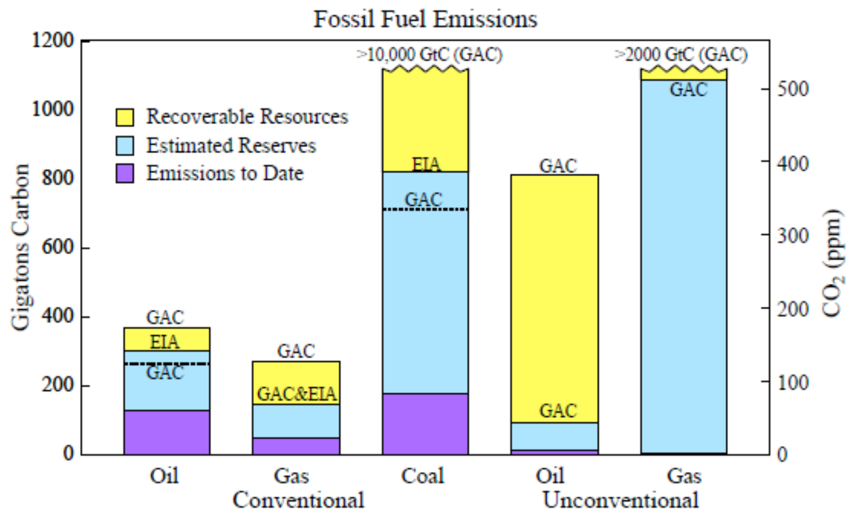

Figure 6. CO_2 emissions by fossil fuels (1 ppm CO_2 ~ 2.12 GtC). Estimated reserves and potentially recoverable resources are from EIA (2011) and GAC (2011).

Implications for Humanity

Burning all fossil fuels would create a different planet than the one that humanity knows. It is clear from paleoclimate data and ongoing climate change that the climate system would be pushed beyond tipping points, setting in motion irreversible changes, including ice sheet disintegration with a continually adjusting shoreline, extermination of a substantial fraction of species on the planet, and increasingly devastating regional climate extremes.

Fossil fuel emissions so far are a small fraction of known reserves and potentially recoverable resources (Fig. 6). There are uncertainties in estimated reserves and resources, especially coal (REFERENCE), some of which may not be economically recoverable with current technologies and energy prices. But there is already more than enough fossil fuel reserve to transform the planet, and fossil fuel subsidies and technological advances will make more and more of the resources available.

We have shown that phase out of fossil fuel emissions is urgent. CO_2 from fossil fuel use stays in the surface climate system for millennia. Failure to phase out emissions rapidly will leave young people and future generations with an enormous clean-up job. The task of extracting CO_2 from the air is so great that success is uncertain at best, raising the likelihood of a spiral into climate catastrophes and efforts to "geo-engineer" restoration of planetary energy balance.

Most proposed schemes to artificially restore Earth's energy balance aim to reduce solar heating, e.g., by maintaining a haze of stratospheric particles that reflect sunlight to space. Such attempts to mask one pollutant with another pollutant almost inevitably will have unintended consequences. Moreover, schemes that do not remove CO_2 will not avert ocean acidification. The pragmatic path is for the world to move expeditiously to carbon-free energies and increased energy efficiency, leaving most remaining fossil fuels in the ground.

Transition to a post-fossil fuel world of clean energies will not occur as long as fossil fuels are the cheapest energy in a system that does not count the full cost of fossil fuels. Fossil fuels are cheap today only because they are subsidized directly and indirectly, and because they do not pay their costs to society, e.g., the costs of air and water pollution caused by extraction and use of fossil fuels with ongoing impacts on human health, food production, and natural ecosystems and with larger future effects from climate change and ocean acidification.

Thus the essential underlying policy, albeit not sufficient, is a price on carbon emissions that allows these costs to be internalized within the economics of energy use. The price should rise over decades such that people and businesses can efficiently adjust their lifestyles and investments to minimize costs. The right price for carbon and the best mechanism for carbon pricing are more matters of practicality than of economic theory.

Economic analyses suggest that a carbon price fully incorporating environmental and climate damage, though uncertain, would be high (Stern, 2007). Ackerman and Stanton (2011) conclude that the cost of climate damage is uncertain by at least a factor of 10, but could be as high as ~\$1000/tCO_2. Such high prices are outside the realm of short-term political feasibility, but prices that high are not necessary to engender a change in emissions trajectory.

An economic analysis indicates that a tax of \$15/tCO_2, rising \$10/tCO_2 per year, could reduce emissions in the United States by 25-30% after 10 years (Reference). Such a reduction of carbon emissions is more than 10 times greater than the carbon content of tar sands oil that would be carried by the proposed Keystone XL pipeline (Reference).

The relative merits of a carbon tax versus cap-and-trade continue to be discussed (Hsu, 2011; other references; also see our Supplementary Material). Cap-and-trade has had some success in Europe, but failed in the crucial arena of U.S. policy, as opponents decisively won the rhetorical battle by describing it as a devious new tax. The merits of an alternative, a gradually rising fee on carbon emissions collected from fossil fuel companies with proceeds distributed to the public, have been summarized by DiPeso (2010), Policy Director of Republicans for Environmental Protection, as: "Transparent. Market-based. Does not enlarge government. Leaves energy decisions to individual choices… Sounds like a conservative climate plan."

A rising carbon price is the *sine qua non* for fossil fuel phase out, but it is not sufficient. Other needs include investment in energy R&D and testing of new technologies such as improved low-loss smart electric grids, electrical vehicles interacting effectively with the power grid, energy storage for intermittent renewable energy, new nuclear power plant designs, and carbon capture and storage. Governments need to support energy planning for housing and transportation, energy and carbon efficiency requirements for buildings, vehicles and other manufactured products, global monitoring systems, and climate mitigation and adaptation in undeveloped countries.

Rhetoric of political leaders, including phrases such as "a planet in peril", leaves the impression that they fully grasp the planetary crisis caused by rising atmospheric CO_2. However, closer examination reveals that much of this rhetoric is aptly described as "greenwash", as even nations considered to be among the "greenest" are supporting expanded fossil fuel extraction including the most carbon-intensive fuels such as tar sands (Hansen, 2009). The reality is that most governments, rather than taking actions to rapidly phase out fossil fuels, are allowing and partially subsidizing continued fossil fuel extraction, including expansion of oil drilling to increasing ocean depths, into the Arctic, and onto environmentally fragile public lands; squeezing of oil from tar sands and tar shale; hydro-fracking to expand extraction of natural gas; and increased mining of coal via mechanized longwall mining and mountain-top removal.

How is it possible that a specter of large human-driven climate change has unfolded virtually unimpeded, despite scientific understanding of likely consequences? Would not governments – presumably instituted for the protection of all citizens – have stepped in to safeguard the future of young people? A strong case can be made that the absence of effective leadership in most nations is related to the undue sway of special financial interests on government policies and effective public relations efforts by people who profit from the public's fossil fuel addiction and wish to perpetuate that dependence (Oreskes and Conway, 2010).

Such a situation, with the science clear enough to demand action but with public understanding of the situation, and thus political response, hampered by the enormous financial power of special interests, suggests the possibility of an important role for the judiciary system. Indeed, in some nations the judicial branch of government may be able to require the executive branch to present realistic plans to protect the rights of the young (Wood, 2009). Plans for emission reductions should be consistent with what the science shows is required to stabilize climate.

Judicial recognition of the exigency and the rights of young people may be helpful in drawing attention to the need for a rapid change of direction. However, fundamental change is unlikely without public support. Obtaining public support probably requires widespread recognition that a prompt orderly transition to the post fossil fuel world, via a gradually rising price on carbon emissions, makes sense and is economically beneficial

The most basic matter, however, is not one of economics. It is a matter of morality – a matter of intergenerational justice. The blame, if we fail to stand up and demand a change of course, will fall on us, the current generation of adults. Our parents did not know that their actions could harm future generations. We, the current generation, can only pretend that we did not know. And that is unforgiveable.

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