Case No. 18-36082

IN THE UNITED STATES COURT OF APPEALS
FOR THE NINTH CIRCUIT

KELSEY CASCADIA ROSE JULIANA, *et al*.,
Plaintiffs-Appellees,
v.
UNITED STATES OF AMERICA, *et al*.,
Defendants-Appellants.

On Interlocutory Appeal Pursuant to 28 U.S.C. § 1292(b)

DECLARATION OF DR. JAMES E. HANSEN IN SUPPORT OF PLAINTIFFS' URGENT MOTION UNDER CIRCUIT RULE 27-3(B) FOR PRELIMINARY INJUNCTION

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I, Dr. James E. Hansen, hereby declare and if called upon would testify as follows:

1. I have been retained as an expert on behalf of Plaintiffs in this matter. I am serving as an expert on a pro bono basis.

2. I have prepared an expert report for this litigation ("Expert Report"), a true and correct copy of which is attached hereto as **Exhibit 1**, which includes Exhibits A through D to my Expert Report. My Expert Report is signed by me. A copy of my Expert Report was served on Defendants on April 13, 2018, except for Exhibits L-R, T, and V to my Expert Report, which contained confidential information of Plaintiffs and were served, subject to the Protective Order, on June 15, 2018.

    a. Attached as **Exhibit 2** to this Declaration is Exhibit E to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in Rayne, Louisiana (relating to Plaintiff Jayden).

    b. Attached as **Exhibit 3** to this Declaration is Exhibit F to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in Satellite Beach, Florida (relating to Plaintiff Levi).

    c. Attached as **Exhibit 4** to this Declaration is Exhibit G to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in Yachats, Oregon.

d. Attached as **Exhibit 5** to this Declaration is Exhibit H to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in Seattle, Washington (relating to Plaintiff Aji).

e. Attached as **Exhibit 6** to this Declaration is Exhibit I to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in Kauai, Hawaii (relating to Plaintiff Journey).

f. Attached as **Exhibit 7** to this Declaration is Exhibit J to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in New York City, New York (relating to Plaintiff Victoria).

g. Attached as **Exhibit 8** to this Declaration is Exhibit K to my Expert Report, true and correct copies of Maps of Projected Sea Level Rise in Manzanita, Oregon.

h. 1981Attached as **Exhibit 9** to this Declaration is Exhibit II to my Expert Report, a true and correct copy of my testimony entitled *Greenhouse Effect and Global Climate Change* delivered on June 23, 1988 before the Senate Committee on Energy and Natural Resources.

3. Climate has always changed, but humans are now the main driver of that change. Increasing atmospheric greenhouse gases are the predominant cause of the relentless global warming of the past 50 years (**Figure 1**), as well as the cause of Earth's energy imbalance that will cause further warming.

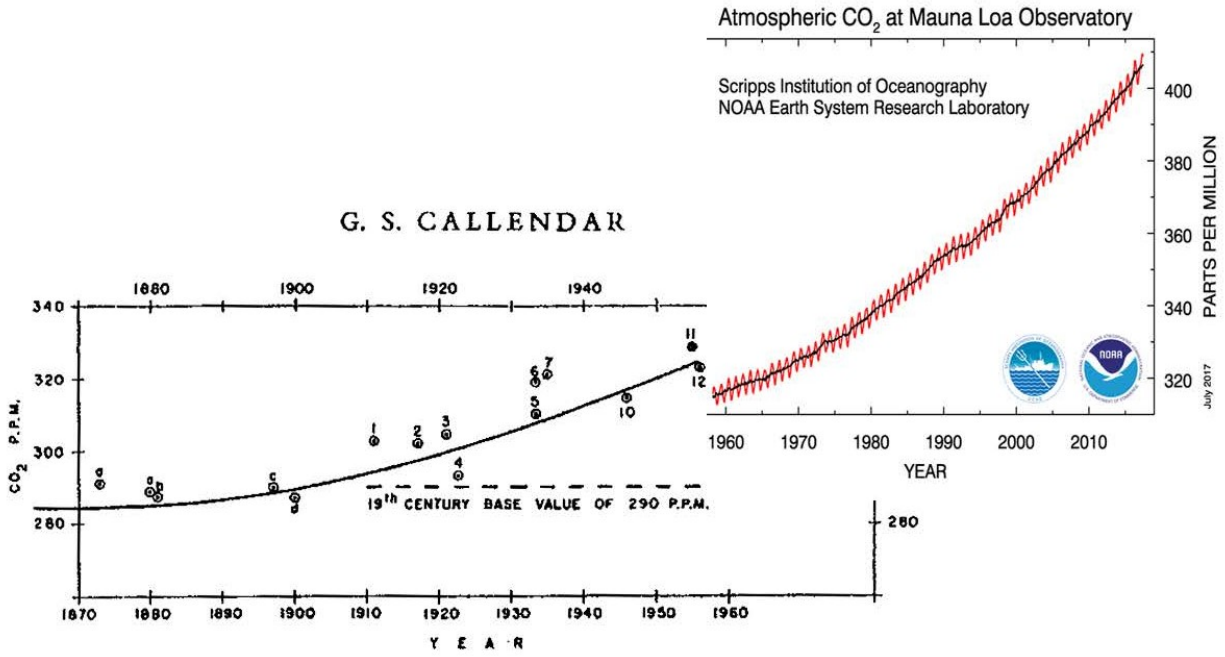

Figure 1.

4. CO_2, primarily a result of fossil fuel emissions, is directly the cause of about 80 percent of the increasing greenhouse gas climate forcing and indirectly it is responsible for part of the remaining 20 percent (mainly CH_4 and N_2O) as warming increases the flux of CH_4 and N_2O into the atmosphere.

5. Climate change is driven by cumulative CO_2 emissions because it is the accumulation of greenhouse gases in the atmosphere, and especially CO_2, that increases the amount of heat energy retained by the air and oceans. Every year of emissions is problematic. The challenge is compounded by the fact that the U.S. has been releasing significant greenhouse gas emissions that have been

accumulating in the atmosphere since the beginning of the industrial revolution.

6. The United States has contributed a disproportionately large share of cumulative global emissions, and thus the United States is, by far, the nation most responsible for the associated increase in global temperatures. Specifically, the U.S. is today responsible for approximately 25% of the cumulative GHG emissions.

7. Current levels of atmospheric greenhouse gases (GHGs), mainly CO_2, cause Earth to be out of energy balance. This imbalance is driving climate change. Earth's energy imbalance is now measured and large. The continual energy gain by Earth is significant. Even during the solar minimum it was equivalent of the energy of 400,000 Hiroshima atomic bombs per day every day of the year.

8. As long as Earth remains out of energy balance, the planet will continue to get hotter. If GHG amounts continue to rise unabated, the energy imbalance will drive global warming to levels with climate impacts beyond the pale.

9. Plaintiffs are already being harmed by Defendants' conduct, past and present, in causing substantial amounts of GHG emissions, but the harm continues to worsen with increasing amounts of fossil fuel development and promotion of fossil fuel energy. If high fossil fuel emissions continue unabated,

consequences will be predominantly negative for humanity, especially for young people, including the Plaintiffs. For example, continued high fossil fuel emissions and the resulting sea level rise will eventually make coastal cities dysfunctional, with incalculable consequences.

10. Actions required to avoid dangerous climate change are guided by Earth's climate history and by the need to restore Earth's energy balance. Science can specify initial targets, sufficient to define policy needs.

11. Substantial emission reductions must begin promptly, or the energy imbalance will be pushed beyond a point whereby human actions can stabilize the climate system in the near-term. It's not possible to know precisely where this point of no return is, but we know it is certain to come, we know we are approaching it quickly, and we know that if we arrive at this point, climate change becomes irreversible for centuries to millennia.

12. Defendants, by continuing to cause climate change, are behaving with flagrant disregard of rights and wellbeing of the public, especially young people. For example, actions by Defendants that cause climate change include authorizing, permitting, and subsidizing massive fossil fuel extraction on federal public lands and waters.

13. In spite of having the scientific knowledge and tools at its disposal to address climate change, Defendants' continue to pursue fossil fuels in the absence of

any coherent, effective national program to reduce fossil fuel emissions. Such an approach, with the scientific knowledge that we have today, is reckless and irresponsible.

14. The following new actions must be halted immediately to buy humanity time to develop a comprehensive climate change mitigation strategy that is scientifically required to stabilize the climate system:

    a. Issuing any new leases or permits allowing mining or extraction of coal on federal public lands or allowing offshore oil and gas exploration, development or extraction; and

    b. Issuing any new permits, authorizations, or approvals that would allow for the development of new fossil fuel infrastructure, including infrastructure related to the exportation of fossil fuels, pipelines, port facilities, liquefied natural gas terminals, or retrofits of existing petroleum refineries to accommodate tar sands oil.

15. The reason these actions must be immediately put on pause is because of the high risk associated with the impending point of no return I describe above. Pursuing these activities that affirmatively result in significant amounts of GHG emissions makes it more likely that we will reach the point of no return faster than we otherwise would. Avoiding that scenario is imperative.

16. **The Scientific Method**: I want to address use of the scientific method in arriving at these opinions, which is based mainly on four papers I wrote in collaboration with relevant world experts. These papers are abbreviated in the text as: Target CO_2 (2008), Assessing Danger (2013), Ice Melt (2016), and Burden (2017).[1]

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[1] A decade ago I asked some of the best relevant scientists in the world to collaborate on a paper to estimate the maximum safe level of atmospheric CO_2, and I was gratified to obtain their expert support. Later papers more directly useful in the opinions addressed in this Declaration required help of additional experts. The resulting four papers contain several hundred references, and are referenced throughout this declaration and my Expert Report.

Target Atmospheric CO2: Where Should Humanity Aim? (2008): Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos, 2008: Target atmospheric CO2: Where should humanity aim? Open Atmos. Sci. J., 2, 217-231, doi:10.2174/1874282300802010217.

Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature (2013): Hansen, J., P. Kharecha, M. Sato, V. Masson-Delmotte, F. Ackerman, D. Beerling, P.J. Hearty, O. Hoegh-Guldberg, S.-L. Hsu, C. Parmesan, J. Rockstrom, E.J. Rohling, J. Sachs, P. Smith, K. Steffen, L. Van Susteren, K. von Schuckmann, and J.C. Zachos, 2013: Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature. PLOS ONE, 8, e81648, doi:10.1371/journal.pone.0081648.

Ice Melt, Sea Level Rise and Superstorms: Evidence From Paleoclimate Data, Climate Modeling, and Modern Observations That 2ºC Global Warming Could be Dangerous (2016): Hansen, J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, I. Velicogna, B. Tormey, B. Donovan, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. LeGrande, M. Bauer, and K.-W. Lo, 2016: Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous. Atmos. Chem. Phys., 16, 3761-3812, doi:10.5194/acp-16-3761-2016.

17. The scientific method is simple in principle: (1) Study all available data on the matter; (2) Be very skeptical of your interpretation; and (3) Reassess from scratch with any new data. However, it comes with one strong caution: Your preference, your ideology, must not affect your assessment. Skill in the scientific method is the highest achievement in science; but in practice it is not easy to achieve.

18. Scientists rely on many tools to understand how the climate system functions and how it will be affected by human-caused GHG emissions. Those include: (1) Earth's paleoclimate history, which contains information about how Earth responded to climate forcings in the past, (2) modern observations of how Earth is responding to natural and human-made climate forcings, and (3) climate models, which aid interpretation of observations and allow projections of future climate change constrained by laws of physics.

19. **Opinion 1**: **Climate has always been changing, as can be seen in Figure 2 below, but is now largely controlled by human activity.**

Young People's Burden: Requirement of Negative CO_2 Emissions (2017): Hansen, J., M. Sato, P. Kharecha, K. von Schuckmann, D.J. Beerling, J. Cao, S. Marcott, V. Masson-Delmotte, M.J. Prather, E.J. Rohling, J. Shakun, P. Smith, A. Lacis, G. Russell, and R. Ruedy, 2017: Young people's burden: Requirement of negative CO2 emissions. Earth Syst. Dynam., 8, 577-616, doi:10.5194/esd-8-577-2017.

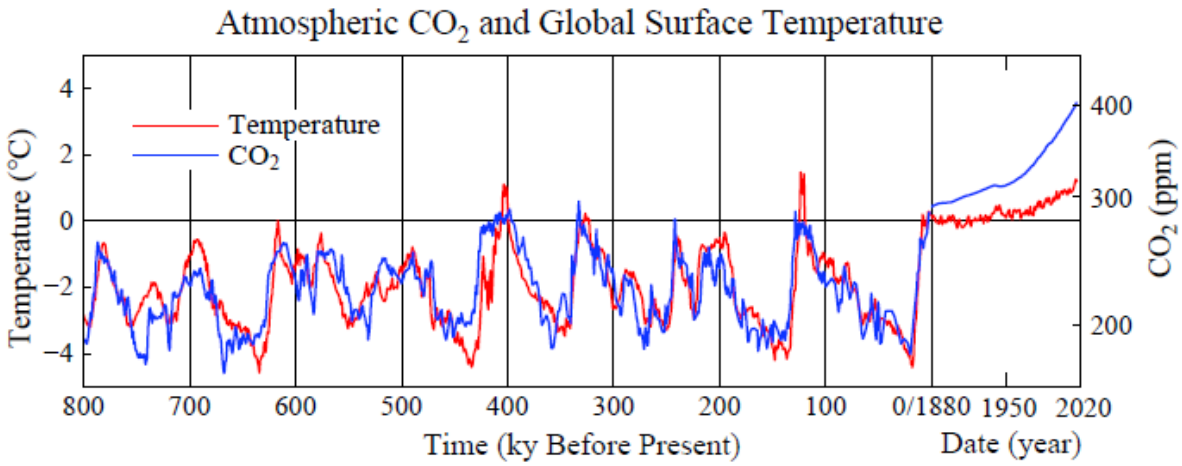


Figure 2. CO_2 amount from Antarctic ice cores (Jouzel et al., *Science*, 317, 793-796, 2007). Paleo global surface temperature change is from ocean core data of Zachos *et al.* (*Nature* 451, 279-283, 2008) via approximations for converting oxygen isotopic data to ocean temperature (Hansen *et al., Phil. Trans. Roy. Soc. A*, 371, 20120294, 2013). CO_2 amount is plotted on a logarithmic scale, because the CO_2 climate forcing and thus expected temperature response are proportional to the logarithm of CO_2 amount.

20. Climate is described as the average weather over some period, including the statistics of weather variability. However, humans have become the principal driver of climate change, overwhelming natural climate variability because rising atmospheric CO_2 levels, primarily a result of the accumulation of fossil fuel emissions, have become the predominant cause of continuing climate change. Increasing CO_2 is now responsible for about 80% of the annual increase in climate forcing by greenhouse gases (GHGs), the other 20% being from the combination of CH_4 (methane), N_2O (nitrous oxide) and other trace gases.

21. Although climate is always changing, the range of variability is limited unless there is some mechanism, some 'forcing,' to drive climate change. A climate

forcing is any physical phenomenon that influences the energy balance of the globe by changing the balance of solar energy that either bounces back into space or remains within Earth's climate system. Climate forcing can result from the accumulation of greenhouse gas emissions, emissions of aerosols (whether from human activity or a volcanic eruption, for example), or the presence or loss of highly reflective ice, among many other physical factors.

22. Natural climate forcings include solar variability. For example, when the Sun becomes brighter, that constitutes a 'positive' forcing. A positive forcing causes global warming, i.e., an increase of global average temperature. In contrast, as an example of a negative forcing, a large volcanic eruption can inject large amounts of gas and dust into Earth's stratosphere that reflect solar radiation back out into space, such as the eruption of Mt. Pinatubo in 1991 that caused a short-term cooling of global temperatures.

23. Human-caused climate forcings now compete with natural forcings, with some human-caused forcings exceeding natural forcings in magnitude. The largest human-made climate forcing is a warming effect due to human-caused changes of atmospheric composition, specifically growth of GHGs such as CO_2, methane, nitrous oxide, and other trace gases that absorb Earth's infrared (heat) radiation. The second largest human climate forcing is a cooling effect due to human-caused increase of atmospheric aerosols. There are additional

human effects, e.g., changes in the characteristics of Earth's surface due to replacement of forests by cropland and the building of highways and cities.

24. Increasing the amount of CO_2 from its pre-industrial level (280 ppm) to the 2018 amount (408 ppm[2]) is causing the most significant, single climate forcing. The CO_2 forcing grows steadily to a large value, while the solar forcing oscillates, never becoming large, so its climate effect is small.

25. Estimating climate change in response to climate forcings would be easy, if there were no climate feedbacks. However, there are many climate feedbacks. For example, atmospheric water vapor increases as Earth warms, as we observe in water vapor change from winter to summer. Increasing water vapor is an amplifying feedback, because water vapor is a strong GHG that adds to the warming. Diminishing feedbacks can also occur. For example, some clouds might become thicker and reflect more sunlight to space as Earth warms.

26. Slow feedbacks include both amplifying and diminishing effects, but empirical evidence shows that the two principal slow feedbacks are both amplifying. The first slow feedback is ice sheet size and albedo (literally its whiteness). Ice sheets shrink as Earth warms. The rock or water surface thus

[2] U.S. National Oceanic and Atmospheric Administration. ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt

exposed is darker than the ice, so it absorbs more sunlight, turns the sunlight into heat, increasing the warming.

27. The second slow feedback is provided by CO_2, CH_4, and N_2O, but mostly by CO_2. The ocean, soil and biosphere release more of these GHGs as the planet gets warmer.

28. Slow feedbacks will begin to come into play this century. Paleoclimate data indicate that the response time of ice sheets and sea level to global warming is one to four centuries. The degree of slow feedback response this century, such as ice sheet mass loss and permafrost melt, will depend on the magnitude of global warming that will be determined by the amount of cumulative GHG emissions. Thus, the actions of the U.S. in the past, as well as the actions of the U.S. today, play a vital role in whether we are able to maintain ice sheets and avoid permafrost melt.

29. The amount of additional global warming from Earth's energy imbalance and from slow feedbacks, can be increased or decreased, if atmospheric GHG amounts increase further or decrease. If emissions decrease at a rate that allows atmospheric GHG amounts to decline, some of the warming in the pipeline can be avoided. The same is true for slow feedbacks: If emissions decrease rapidly such that atmospheric GHG concentrations stabilize and then

slowly decline, those dangerous slow feedbacks of ice sheet loss and permafrost melt can be avoided to a significant degree.

30. The long response time of the ocean and slow climate feedbacks enables the build-up of severe consequences for young people and future generations, all while most of the public does not notice much happening, as noticeable climate change is just beginning to rise above natural variability. In that regard, the ocean's inertia and the slow climate feedbacks create a significant problem for young people. However, this long response time also provides an opportunity to avoid the worst consequences, if emissions are decreased rapidly such that atmospheric GHG concentrations are first stabilized by radically reducing emissions and then decreased through practices that draw down carbon dioxide out of the atmosphere and sequester it permanently.

31. Global temperature, despite its natural variability, has been rising rapidly for 50 years**,** at a rate 0.17°C/decade (0.3°F/decade). This warming continues unabated and has accelerated in the past decade, as revealed by connecting the most recent El Niño maxima and La Niña minima (**Figure 3**).

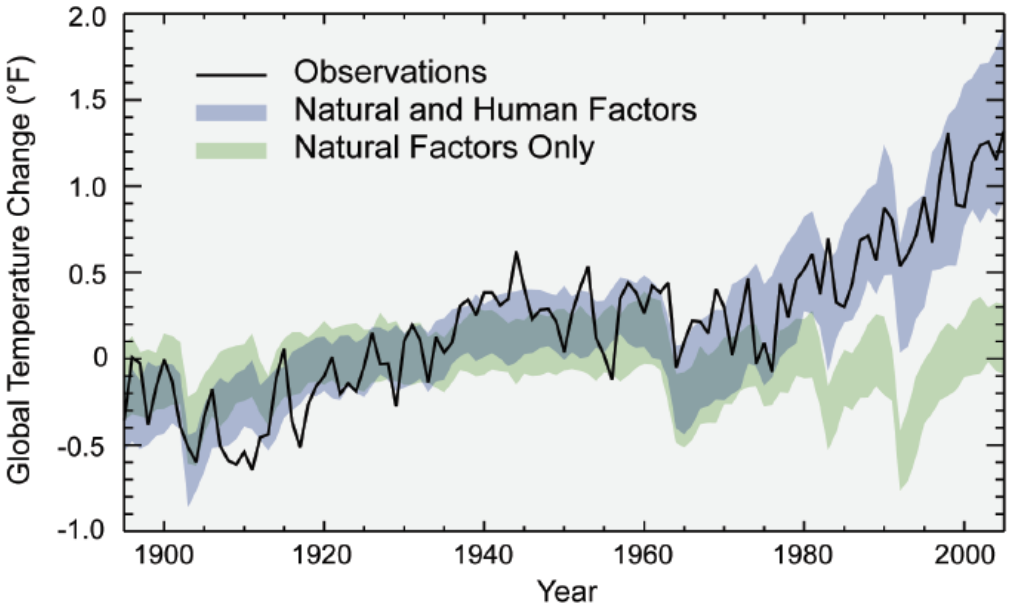


Figure 3. Modeled and observed global temperature, from Melillo, J. M., et al., Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U. S. Global Change Research Program, 841 pp., who adapt the figure from Huber, M. and R. Knutti: *Nature Geosci,* 5, 31-36, 2012.

32. Global warming has unquestionably risen out of the range of natural variability. The green band shows how global temperature would have changed due to natural forces alone (including solar and volcanic activity), as simulated by climate models. The blue band shows model simulations for both human and natural forcings. The black line is observed global temperature. Only with the inclusion of human influence can models reproduce the observed temperature changes.

33. We know the modern era temperature will continue to rise. Earth is out of energy balance, with more energy coming in than going out, so it is certain

that global warming will continue on decadal time scales, unless there are significant reductions in GHG emissions.

34. How much further will temperature rise if we leave atmospheric CO_2 at its current amount (about 408 ppm) indefinitely? The eventual warming for 408 ppm CO_2 will be about 3.5°C, including the full effect of both fast and slow climate feedback processes. The consequences of a warming of this amount would be unimaginably expensive and extremely devastating. In summary, Earth is now substantially out of energy balance. The amount of solar energy that Earth absorbs exceeds the energy radiated back to space. The principal manifestations of this energy imbalance are continued global warming on decadal time scales and continued increase in ocean heat content.

35. **Opinion 2: The United States is substantially responsible for the climate change impacts Plaintiffs are experiencing today.** China passed the United States in annual fossil fuel CO_2 emissions several years ago and now has annual CO_2 emissions more than double those of the United States. However, we showed (Hansen et al., Atmos. Chem. Phys., 7, 2287-2312, 2007) that global warming is proportional to cumulative emissions and others have since confirmed that finding. Cumulative emissions by the United States substantially exceed those of any other nation. Thus, the United States is, by

far, more responsible than any other nation for the associated increase of global temperature.

36. Per capita emissions provide another useful perspective on GHG emission responsibilities. Cumulative per capita emissions of China and India are an order of magnitude smaller than U.S. emissions.

37. The United States therefore has an outsized responsibility for human-made climate change. The United States also has exceptional technical potential to reduce its emissions and work in mutually beneficial ways to enable other nations to reduce their emissions.

38. Opinion 3: If high fossil fuel emissions continue, global warming will have predominantly negative consequences for humanity, especially for young people, including these Plaintiffs.

39. Sea level changes sensitively with global temperature. Ocean warming is melting ice shelves that buttress the Antarctic and Greenland ice sheets. If global warming continues unabated, portions of the ice sheets will become unstable, ice sheet disintegration will accelerate, and sea level will rise continuously.

40. A majority of large U.S. and global cities are coastal. Continued high fossil fuel emissions will lead to eventual sea level rise that makes these cities dysfunctional, with consequences that are incalculable. As Earth becomes

warmer the ice sheets shrink and sea level rises. Sea level history for the past several hundred thousand years provides an indication of how much ice sheet size (as measured by sea level) adjusts in response to global temperature change on these time scales (**Figure 4)**.

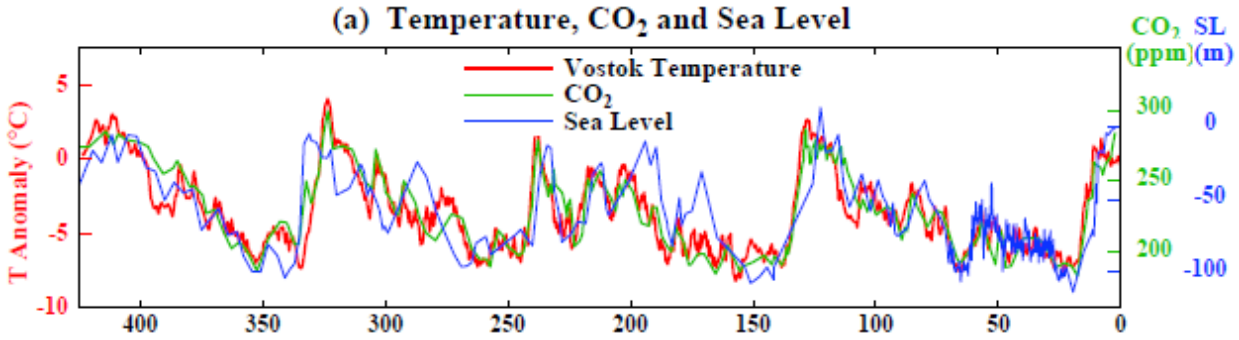


Figure 4. Antarctic temperature (Vimeux et al. 2002), atmospheric CO_2 (Petit et al. 1999) and sea level (Siddall et al. 2003) over past 420,000 years. Figure from Hansen, J., M. Sato, P. Kharecha, G. Russell, D.W. Lea and M. Siddall, *Phil. Trans. R. Soc. A*, **365**, 1925-1954, 2007, which provides data sources.

41. Sea level change is of order 100 meters for a global temperature change of at most 5°C (Antarctic temperature change of about 10°C), thus 20 meters (about 65 feet) for each degree Celsius of warming. Sea level rise **in Figure 4** was mainly from ice ages, when there were ice sheets on North America and Eurasia as well as Greenland and Antarctica, toward warmer climate, so there were more ice sheets to provide meltwater. Sea level will not be as sensitive in going from today's climate toward warmer conditions. However, sea level reached heights as great as 6-9 meters during the prior interglacial period, the

Eemian, about 120,000 years ago, when global temperature was only about 1°C above the pre-industrial level, i.e., similar to today's global temperature.

42. During the early Pliocene, several million years ago, when global temperature was at most about 3°C warmer than pre-industrial conditions, sea level probably reached as high as 15-25 meters (49-82 feet) above today's level.

43. In other words, there is plenty of vulnerable ice available to cause eventual sea level rise that would inundate today's coastal cities, in response to a warming level that we could produce this century. Burning all of the readily available fossil fuels would eventually melt almost all the ice on the planet, raising sea level 65-75 meters (more than 300 feet). Greenland is at a lower latitude than Antarctica and thus has much more surface melt in the summer. The area of surface melt has more than doubled since satellite measurements began in the late 1970s. Snowfall on Greenland is also increasing because atmospheric water vapor increases as Earth warms. Increased snowfall is a positive term in the ice sheet's mass balance that partially offsets increased melting. However, not surprisingly, the net effect is that the Greenland ice sheet is shrinking as the world gets warmer.

44. Ice sheet mass loss will not grow linearly, simply proportional to the temperature increase. The existence of amplifying feedbacks implies that mass loss from the most vulnerable portions of the ice sheets is likely to be a

very nonlinear process that can be approximated by a doubling time for the rate of mass loss. The characteristic time for ice sheet mass loss, approximated as a doubling time, may be longer for Greenland than for Antarctica, because Greenland does not have as much ice in direct contact with a warming ocean as Antarctica does. However, Greenland does have several fjords with ice streams that terminate in the ocean, so Greenland is not immune to marine interactions that can speed up mass loss. Antarctica has extensive ice shelves extending into the ocean, which are now melting faster as the ocean warms. Ice shelf loss is beginning to cause increased discharge of land-based ice, which tends to freshen the surface waters around Antarctica and produce feedbacks that will amplify continental ice loss. As yet the rate of freshwater injection onto the Southern Ocean may not have yet reached a level large enough to counter the loss of sea ice due to global warming, as judged from the large sea ice area reduction that has accompanied the warming of the past few years.[3]

45. Nevertheless, it is clear that amplifying feedbacks will produce increasingly rapid sea level rise if fossil fuel emissions and global temperatures continue to increase unabated. Even in the case of slowly changing paleoclimate forcings, ice sheet disintegration on a number of occasions achieved a rate that

[3] Sea Ice Area, http://www.columbia.edu/~mhs119/SeaIceArea/ (last visited Feb. 6, 2019).

produced meter and multi-meter sea level rise in a century, confirming the existence and the potential large magnitude of amplifying feedbacks.

46. Once the global warming effect on ice sheets is sufficient to strongly spur the amplifying feedbacks, we would expect the rate of mass loss by the ice sheets and the rate of sea level rise to grow nonlinearly, at a faster and faster rate. Amplifying feedbacks win out eventually in a warming climate. The magnitude of eventual sea level rise for a given global warming is indicated by the repeated examples in paleoclimate records. We must expect several meters of sea level rise for each degree Celsius of global warming, if warming is left in place indefinitely.

47. Sea level rise is beginning to be noticed in places, as Plaintiff Levi has experienced first-hand. However, the consequences are small compared with what is in store if high fossil fuel emissions and global warming continue. Sea level reached at least six meters greater than today during the Eemian period, when global temperature is estimated to have been about 1°C warmer relative to pre-industrial, i.e., little warmer than today, if at all.

48. Projections for end-of-century warming reach 3°C, if business-as-usual fossil fuel use continues, a global warming that could yield eventual 15-25 meter sea level rise.

49. With sea level rise of this magnitude, all of the large cities on the East Coast of the United States – Boston, New York, Philadelphia, Washington, Miami – would become dysfunctional and abandoned, even though portions of the cities would remain above the rising waters. The infrastructure in our coastal cities is a large fraction of our infrastructure. Much of our transportation system in the Eastern United States, including railroads and highways, would be dysfunctional. Our largest airports would be under water, including all of those serving New York.

50. It would not be sensible to rebuild on the shore, as there would be no stable shoreline. If ice sheets are allowed to destabilize – that is if fossil fuel emissions are not rapidly phased out -- then shorelines will be lost in the face of continual sea level rise lasting centuries, a consequence of the slow response time of ocean temperature and ice sheet dynamics. Ice sheet disintegration is a process that is slow to get started, but exceedingly difficult to stop once it is well underway – making it irreversible in the timeframe of these plaintiffs if it gets to a tipping point.

51. The great danger for young people, is that they are being handed a situation that is out of their control, a situation made more egregious due to the fact that the Defendants have a complete understanding of precisely how dangerous the situation is that they are handing down to these Plaintiffs.

52. Extreme hot summers in the tropics, of a degree that seldom occurred last century, have become much more common. At middle latitudes climate change is not so obvious in the winter, but the chance of having an extremely hot summer has increased noticeably. The largest change from the normal climate of last century is in the subtropics in summer and the tropics year-round. Subtropics includes the Southwest United States and the Mediterranean/Middle East region. Every summer in these regions is now hotter than the average summer of last century. The subtropics in the summer and the tropics year-round were already hot, before the rapid warming trend of the past 50 years. These areas will become dangerously hot, and an unpleasant place to live, if global warming continues.

53. The principal effect of global warming on regional climate is to increase climate extremes, at both ends of the hydrologic cycle. Places and times when it is dry can have stronger droughts, because of greater heat. Fire seasons will be more intense and longer. Dry subtropics, such as the Southwest United States where Plaintiff Jaime lives, will, in general, become still hotter and drier, if fossil fuel emissions and global warming continue unabated.

54. Even such regions, however, will have more extreme rainfall events and floods during the rainy season or the occasional storm. The reasons for this are that warmer air holds more water vapor and the sea surface is warmer.

Water vapor is fuel for thunderstorms, tornadoes, and tropical storms, and with a warmer sea surface tropical storms are able to reach higher latitudes and to come onshore with greater strength. Rising sea level adds to the height of storm surges. The greatest damage is often caused by the increased rainfall and thus greater flooding associated with higher temperatures. Global warming can also slow the translational movement of tropical storms in some situations. Slow storm movement greatly increased rainfall totals and flood damage from recent hurricanes hitting the United States, specifically the Houston area in 2017 (Hurricane Harvey) and the Carolinas in 2018 (Hurricane Florence).

55. In summary, continued high fossil fuel emissions would hand young people a situation with consequences that are devastating and impossibly expensive. Impacts of fossil fuel burning on sea level and on regional climate raise great practical and moral issues on a global scale. First the climate change that drives this injustice is caused mainly by cumulative fossil fuel emissions. The United States is far more responsible for those accumulated emissions than any other nation. The United States also possesses sufficient fossil fuel resources, in coal and other conventional and unconventional fossil fuels, which through development, use, and exportation, can substantially drive the climate system, causing young people to inherit a climate system with

consequences running out of their control. There must be an immediate phasedown of fossil fuel emissions at the rate needed to stabilize atmospheric composition and climate.

56. **Opinion 4**: **Actions required to avoid dangerous climate change are guided by Earth's climate history and by the need to restore Earth's energy balance.** Science can specify an initial target for atmospheric CO_2, about 350 ppm, which is sufficient to define near-term policy needs.

57. Earth's climate history shows the eventual climate effect of different levels of atmospheric gases. CO_2 is dominant, by far, of the long-lived greenhouse gases, and thus CO_2 operates as a control knob on global temperature. Earth does not respond instantly to CO_2 changes. First, there is a lag due to the ocean's large thermal inertia: 100 years after a change of atmospheric greenhouse gases, such as a release of emissions from burning fossil fuels, Earth's surface only reflects 2/3 of the consequent warming. Second, the ice sheets on Antarctica and Greenland shrink as Earth becomes warmer, but melting takes time: paleoclimate data show that sea level change lags global temperature change by 1-4 centuries. However, we cannot count on a long ice sheet lag, because the human-made CO_2 change is large and much faster than natural CO_2 changes that drove paleoclimate sea level changes. The fortunate side of ocean and ice sheet lag is that, despite the large size of the atmospheric

CO_2 increase, global warming has been limited (to just over 1°C, or about 2 degrees Fahrenheit) and sea level rise is small (about 20 cm, which is about 8 inches). The unfortunate side is that more temperature rise, and a lot more sea level rise, are 'in the pipeline', unless we reduce the amount of CO_2 in the air.

58. Global warming of +2°C relative to preindustrial climate would make Earth warmer than it was in the Eemian interglacial period when sea level reached 6-9 meters (20-30 feet) higher than today. If global temperature reaches +2°C, ocean temperature will remain elevated for centuries, so sea level rise of many meters almost certainly would be locked in. Most coastal cities would be lost. Civilization is adapted to today's shorelines, with more than half of today's largest cities being coastal.

59. Clearly a 2°C lid on warming would be a foolish target to set, highly dangerous for young people and future generations. Civilization is adapted to the climate of the Holocene. Human-caused global warming of about 1°C already is harming the Plaintiffs. If global warming were doubled to 2°C many regions would become difficult to live and work in.

60. Further warming in cold regions is also undesirable, judging from changes that are beginning, such as the melting of tundra. If fossil fuels are allowed to cause 2°C global warming, the CH_4 and CO_2 released from melting tundra and methane hydrates (frozen methane and water found in deep ocean and arctic

ecosystems) will amplify that warming to still greater levels. Arctic summer sea ice is already much diminished with 1°C global warming and might pass a tipping point leading to much larger loss with major impacts on Arctic ecosystems.

61. Regional climate extremes are already enhanced at 1°C global warming, including more extreme floods, storms, heat waves and wildfires. Observed climate impacts from 1°C global warming point to the conclusion that it is dangerous to push ahead to still greater global warming.

62. The target <350 ppm for global atmospheric CO_2 set in 2008, when CO_2 was 385 ppm and global warming was +0.9°C, emphasized that 350 ppm was only an initial target that must be refined once CO_2 actually begins to decline and approach 350 ppm. Earth's energy imbalance was only one of several reasons for choosing the initial target <350 ppm.

63. Other reasons included paleo data on climate and sea level for larger CO_2 amounts, effects of ocean acidification, and climate impacts already emerging in 2008 when the global temperature anomaly was +0.9°C.

64. **Opinion 5: Immediate and significant GHG emission reductions are needed to restore Earth's energy balance.** GHG emission reductions at a substantial rate must begin promptly. Our ability to turn back the dial will not

long persist, as climate can be pushed beyond a point at which changes proceed out of human control.

65. Leisurely reductions of 1-2% per year will not suffice, and continued increases of 3.9% would be calamitous. The CO_2 released from burning fossil fuels remains in the climate system for millennia (Archer, 2005). The portion of CO_2 remaining in the air declines rapidly at first. Half of the emitted CO_2 is taken up in the first 25 years by the ocean, soil and biosphere, but uptake then slows such that almost one-fifth is still in the air after 500 years. Chemical weathering eventually deposits the fossil fuel carbon on the ocean floor as carbonate sediment, but that process requires millennia.

66. There are three slow processes that characterize the climate and energy problem, creating a difficult situation for young people, including these Plaintiffs. Unless urgent actions are undertaken, climate consequences will run out of humanity's control.

67. First, Earth responds to the energy imbalance by growing warmer, until it radiates to space as much energy as it absorbs from the Sun. However, it takes at least several decades for the ocean to achieve most of its warming. Meanwhile, ice sheets and tundra are melting, providing amplifying feedbacks that increase the warming and stretch the response time. Much of the fossil

fuel CO_2 injected into the air remains in the atmosphere for centuries**. Figure 5** shows how difficult the problem becomes if high emissions continue.

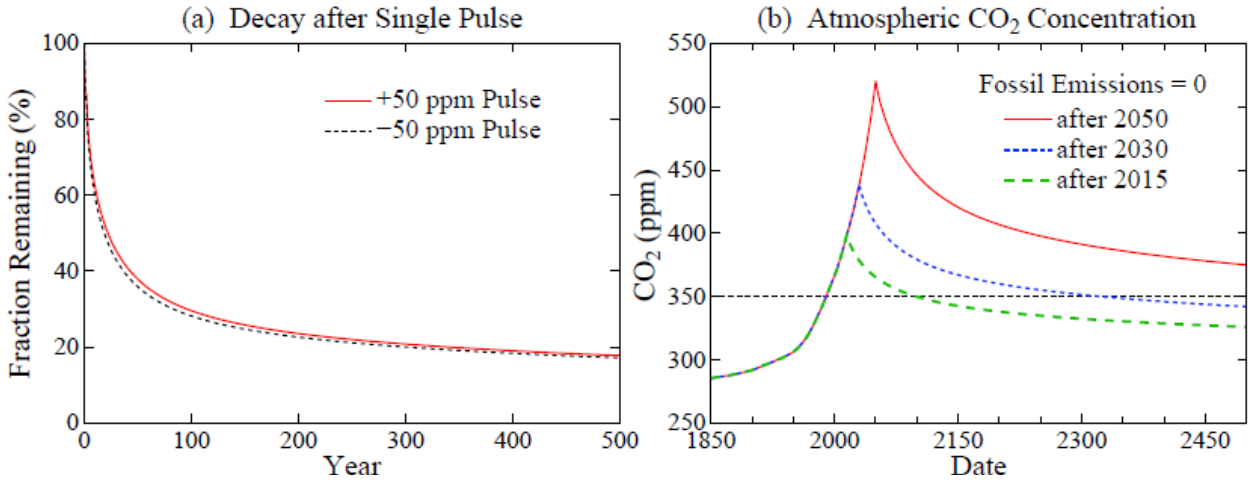


Figure 5. Decay of atmospheric CO_2 perturbations. (A) Instantaneous injection or extraction of CO_2 with initial conditions at equilibrium. (B) Fossil fuel emissions terminate at the end of 2015, 2030 or 2050.[10]

68. The process controlled by humans, fossil fuel emissions, will dominate the climate outcome. The potential danger of this situation if high emissions continue, predictable catastrophic consequences in future decades, is manifest. The task is to reduce emissions faster than Earth responds to the energy imbalance. As we will see, there is no time for delay in reducing emissions.

69. **Figure 6** shows GHG emissions scenarios in by the annual growth rate of emissions: +2%, 0% (constant emissions),-3% and-6%.

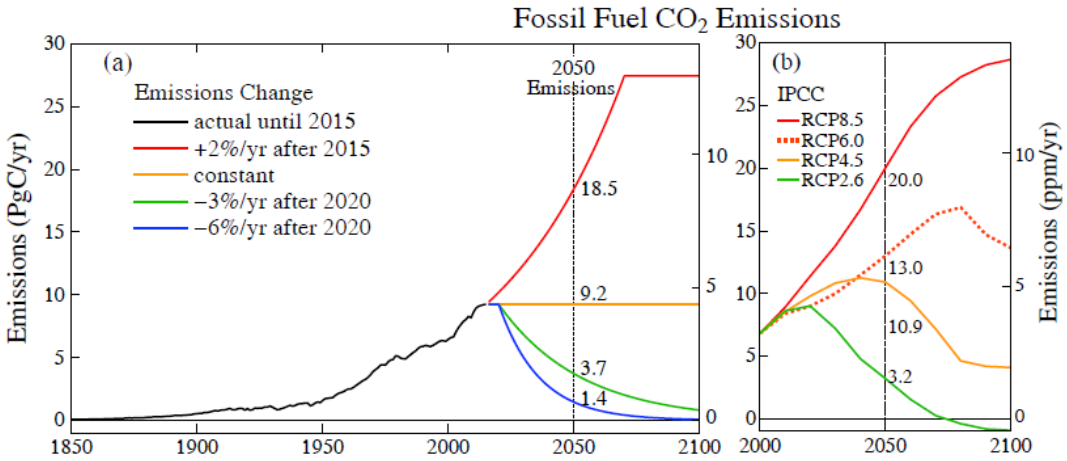


Figure 6. Fossil fuel emission scenarios. (a) Scenarios with simple specified rates of emission increase or decrease. (b) IPCC (2013) RCP scenarios. Note: 1 ppm atmospheric CO_2 is ~2.12 GtC.

70. The atmospheric CO_2 amount resulting from each emission scenario can be computed with confidence using carbon cycle models for the uptake of CO_2 by the ocean, biosphere and soil. The model used here is a convenient well-tested version of the Bern model (Joos et al., 1996) as also described by Kharecha and Hansen (2008) and references therein.

71. Rapid emission reduction, at least 3% per year, is needed just to keep CO_2 in the neighborhood of 400 ppm. Constant emissions lead to CO_2 above 500 ppm this century. Emissions growth at 2% per year, typical of recent decades, leads to CO_2 exceeding 800 ppm! In other words, current policies by Defendants in this litigation yield a path that leads to certain disastrous consequences for young people and future generations.

72. Consider the case of constant emissions, which would result in CO_2 of 547 ppm in 2100 without CO_2 extraction. That constant emission scenario can still

achieve the goal of 350 ppm CO_2 in 2100, provided that 695 PgC[4] of CO_2 is captured and permanently stored. The economic burden of capturing and storing this amount of CO_2 is staggering. This low cost range of Smith et al. is obtained for biophysical extraction methods with economic co-benefits, such as energy production, that reduce the cost. In contrast, the lowest cost for direct air capture of CO_2 based on technology demonstration (Keith et al., 2018) is \$113-232/tCO_2 and that cost does not include cost of CO_2 storage, which has been estimated as \$10-20/tCO_2.

73. Now, let us accept the low cost range of Smith et al., \$40-95/tCO_2, and calculate the cost of extracting the 695 GtC that must be removed under the "constant emissions" scenario, if atmospheric CO_2 is to be brought down to 350 ppm by 2100. The result is \$104-243 trillion, or \$1.3-3.0 trillion/year if the cost is divided uniformly over 80 years. Such extraordinary cost, along with the land area, fertilizer, and water requirements (Smith et al., 2016) suggest that, rather than the world being able to buy its way out of climate change, continued high emissions would likely force humanity to live with climate change running out of control with all the consequences that would entail.

[4]A PgC (petagram of carbon) is the same as a GtC (gigaton of carbon), i.e., one billion tons of carbon. Note that if one prefers to use the mass of CO_2, these numbers must be multiplied by 44/12 ~ 3.67, to account for the atomic mass of carbon being 12 and the mass of oxygen being 16.

74. These considerations reveal the unlikely prospects for CO_2 extraction, that is, negative emissions, to serve as a climate panacea. Almost all economists agree that reduction of emissions is not only possible, it is the economically sensible approach. Rapid rates of fossil fuel phasedown are not only possible, they make the most economic sense. Climate simulations of global temperature change provide valuable guidance about the rate at which CO_2 emissions must be reduced to stabilize climate.

75. Emission reductions of 3 percent/year, or more, are needed to stay below 1.5°C global warming and achieve a downward temperature trend. Decreasing temperature would tend to limit slow feedback amplifications. Extraction of CO_2 from the air is required, in addition to emission phasedown, in order to bring global temperature back close to the Holocene range. Without extraction of CO_2, global temperature remains well above the Holocene level for centuries, leaving a danger of consequences such as large sea level rise, albeit such consequences are not as certain as they are with constant emissions consistent with the status quo of today.

76. **Opinion 5**: **In pursuing and promoting fossil fuels, the United States government is behaving with flagrant disregard of the rights and wellbeing of the Plaintiffs.**

77. For decades, the long-approaching threat of climate change was well understood by both the Defendants and the scientific community.[5] Based on simple climate models, temperature measurements at weather stations, and limited paleoclimate data, colleagues and I were able, as early as 1981, to anticipate discernible warming for the 1980s and 1990s, and 21st century shifts in climate zones, increasing climate extremes, eroding ice sheets, and accelerated sea level rise.

78. Our work analyzing paleoclimate data corroborated earlier estimates of climate sensitivity for a doubling of atmospheric concentrations of CO_2 and led us to conclude, and warn the government, that all fossil fuels could not be burned without untenable consequences for future generations.

79. The highest levels of the U.S. government have had long-standing knowledge of the scientific work that was being done. For example, Charney, et al. reported to the Executive Office of the President in 1979 that future climate change would cause severe impacts on future generations in the 21st century, referring to their findings about inevitable warming as "disturbing to policymakers." Charney advised the Executive Office of the President: "A

[5] A more comprehensive history of the scientific understanding of climate change, and the government's knowledge of that science, is set forth in my Expert Report, attached hereto as **Exhibit 1**.

wait-and-see policy may mean waiting until it is too late" and suggested their findings should be a guide to policy makers.

80. In 1988 and again in 1989 I testified in the U.S. Senate to explain that the global warming we were seeing was large enough that we could then ascribe, with a high degree of confidence, a cause and effect relationship between measured warming and human caused greenhouse gas emissions.

81. In 1992 the United States helped draw up the United Nations Framework Convention on Climate Change. The objective of the Framework Convention is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The United States is among 197 nations that signed the Framework Convention, which went into force in 1994. The Framework Convention states that Parties should act to protect the climate system on the basis of "common but differentiated responsibilities" and that developed country Parties should "take the lead" in addressing climate change. The Convention outlines how specific international treaties, called Protocols or Agreements, may be negotiated to specify limits on greenhouse gas emissions, but it has no enforcement mechanisms, and the United States has not agreed to any emission reductions. The United States did not join the 1997 Kyoto Protocol,

which established "binding" targets for national emissions, but with no enforcement mechanism.

82. Instead, the U.S. government has doubled down on extraction of even more fossil fuels, including the dirtiest, most carbon-intensive unconventional fossil fuels.[6] Defendants have allowed, permitted, and subsidized fossil fuel interests to exploit fossil fuel reserves, so that the fossil fuels are processed, transported, and burned with little or no control on emissions. Defendants allow the atmosphere to be treated as a free dumping ground for waste CO_2. Defendants do this even while knowing the consequences thereof, which is ill-advised.

83. The Obama Administration, for example, in 2011 opened up hundreds of millions of tons of coal on public lands to new lease sales. Moreover, the sales were at prices far below market value, continuing a practice of federal subsidy of coal titans amounting, through those sales alone, to tens of billions of dollars. The Trump Administration's astounding recent efforts to accelerate fossil fuel CO_2 emissions are pressing the world more rapidly toward the climate precipice. In spite of the scientific knowledge about the dangers of climate change, the U.S. continues its fossil fuel-based energy system in the

[6] *See* my Expert Report for a more thorough description of how Defendants have continued to pursue fossil fuels in spite of the scientific knowledge being collected about the dangers of climate change.

absence of any coherent, effective program to reduce emissions, which, unless remedied, unarguably sentences young people to either a massive, implausible cleanup or growing deleterious climate impacts, or both. Defendants have no plan to phase down fossil fuel emissions and move to clean energy alternatives, even though Defendants themselves have produced numerous reports showing that such planning is urgent.

84. On 23 November 2018, the U.S. Global Change Research Program issued the Fourth National Climate Assessment, on Impacts, Risks and Adaptation in the United States. The assessment began: "Earth's climate is now changing faster than at any point in the history of modern civilization, primarily as a result of human activities. The impacts are already being felt in the United States and are projected to intensify in the future – but the severity of future impacts will depend largely on actions taken to reduce greenhouse gas emissions . . . ." This clearly shows that the Defendants know what is going on with the climate system, yet they continue to pursue fossil fuels, to the known detriment of these Plaintiffs.

85. **SUMMARY OF OPINIONS**: The climate science described above shows unambiguously that global fossil fuel emissions must decrease rapidly if young people, including these Youth Plaintiffs, are to avoid climate

calamities. Urgency is exposed by one last graph: the annual addition to the human-caused increase in radiative forcing **(Figure 7).**

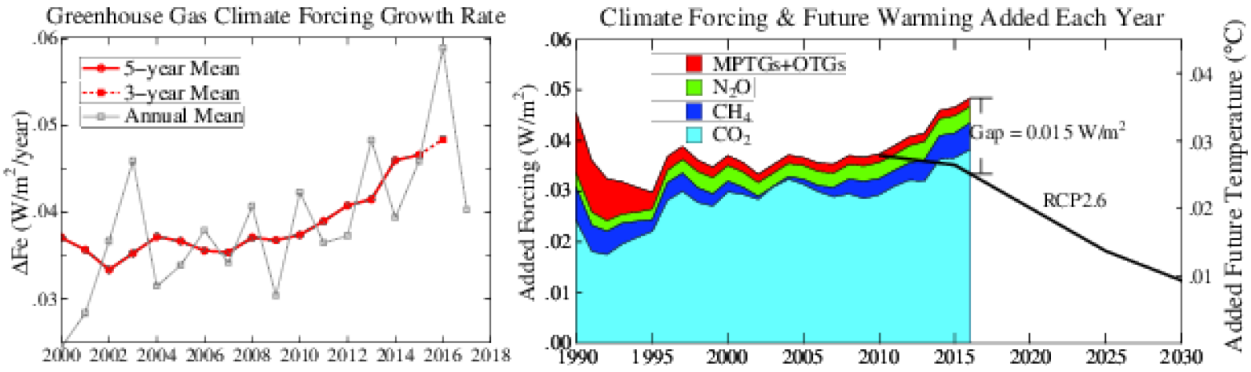


Figure 7. Annual increase of greenhouse gas climate forcing. Right graph: contribution of each gas. RCP2.6 scenario is designed to keep global warming below 1.5°C, but it is being exceeded. Added future warming (scale on right) is based on climate sensitivity 3°C for $2\times CO_2$, i.e., it excludes slow feedbacks.

86. This forcing (measured in W/m^2) caused by the greenhouse gas increase is known accurately and based on a simple radiation calculation that does not depend on climate models or climate sensitivity. It is, instead, a function of the reduction of Earth's heat radiation to space, which reduction increases Earth's energy imbalance.

87. Right now, Defendants are persisting in their conduct that will worsen the energy and climate trajectory. Accordingly, a cold dose of reality, which **Figure 7** delivers, is now important. **Figure 7** compares reality with the United Nations Intergovernmental Panel on Climate Change ("IPCC") scenario RCP2.6, the pathway for climate forcing that the IPCC identified as required to cap global warming at about 1.5°C.

88. Already the gap between that scenario and reality has grown to 0.015 W/m^2 and measurements in 2018 show that the gap is continuing to grow. The IPCC realized that unfettered fossil fuel emissions would cause growth of atmospheric greenhouse gases to outstrip scenarios in which global warming is limited so as to avoid dangerous consequences. Thus, they devised a scenario, RCP2.6, in which large quantities of CO_2 are assumed to be stripped from the air, so as to make up for any failure to achieve emission reductions.

89. Atmospheric CO_2 must be reduced almost exactly 1 ppm CO_2 to increase heat radiation to space by 0.015 W/m^2.[7] One ppm of CO_2 is 2.12 billion tons of carbon or about 7.77 billion tons of CO_2. Recently Keith et al. (2018) achieved a cost breakthrough in carbon capture, demonstrated with a pilot plant in Canada. Cost of carbon capture, not including the cost of transportation and storage of the CO_2, is $113-232 per ton of CO_2. Thus, the cost of extracting 1 ppm of CO_2 from the atmosphere is $878-1803 billion.

90. In other words, the cost, in a single year, of closing the gap between reality and the IPCC scenario that limits climate change to +1.5°C is already about $1 trillion. That is without the cost of transporting and storing the CO_2, or

[7] We actually need to suck more than 1 ppm from the air, because the ocean reacts to the reduction of atmospheric CO_2 by increasing the net backflux of CO_2 to the atmosphere. However, we can make our point without including this added difficulty in achieving CO_2 drawdown.

consideration of whether there will be citizen objection to that transportation and storage.

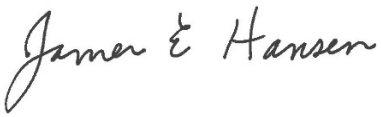
91. This annual cost will rise rapidly, unless there is a rapid slowdown in carbon emissions. This annual cost is not being paid, and common sense tells us that it will not be paid in the future as the cost rises to astronomical levels.

92. Instead the mess is left for young people. Continued high fossil fuel emissions sentences young people to a massive and likely implausible cleanup and growing deleterious climate impacts. The tragedy of the intergenerational issue of human-made climate change is that it is unnecessary and preventable, but only if Defendants act urgently and effectively.

93. These youth Plaintiffs confront an imminent gathering storm. They have at their command considerable determination, a dog-eared copy of our beleaguered Constitution, and rigorously developed science. The Court must decide if that is enough.

In accordance with 28 U.S.C. § 1746, I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on February 6, 2019.

Respectfully submitted,



James E. Hansen

TABLE OF ACRONYMS AND ABBREVIATIONS

AGU: American Geophysical Union
AMOC: Atlantic Meridional Overturning Circulation
BAU: business as usual
C: Celsius
CH4: methane
CO2: carbon dioxide
EPA: U.S. Environmental Protection Agency
F: Fahrenheit
GCM: global climate model
GISS: Goddard Institute for Space Studies
GHG: greenhouse gas
GNP: gross national product
GtC: gigatonnes of carbon
IPCC: United Nations Intergovernmental Panel on Climate Change
MBM: mass budget method
NAS: National Academy of Sciences
NASA: National Aeronautics and Space Administration
NOAA: National Oceanic and Atmospheric Administration
NRC: National Research Council
N2O: nitrous oxide
PETM: Paleocene-Eocene Thermal Maximum
ppm: parts per million
SLR: sea level rise
SMIRC: The Study of Man's Impact on Climate
SO2: sulfur dioxide
UNFCCC: United Nations Framework Convention on Climate Change
W/m2: Watts per square meter