Information in Support of Science-Based Targets Discussion

Climate and Energy Action Planning (CEAP) Committee

For the October 15, 2016 CEAP Meeting

Compiled by Marni Koopman

10-6-2016

Attached are the following materials:

A. Dr. James Hansen's recent paper called Young People's Burden, Oct. 4, 2016, based on his most recent scientific publication to the journal Earth System Dynamics.
B. A video link (embedded within Young People's Burden)
C. Comments on the State of Washington's Clean Air Rule, issued by the Western Environmental Law Center when the state failed to meet a Court order to develop a rule limiting greenhouse gas emissions by the end of 2016.
D. James Hansen's declaration in support of the Western Environmental Law Center's comments on the proposed Clean Air Rule for the state of Washington
E. Hansen et al. 2013. Assessing "dangerous climate change": required reduction of carbon emissions to protect young people, future generations, and nature. PLoS One 8(12).
F. A recent review of a publication showing that reservoirs are major emitters of methane, a greenhouse gas 34 times more potent than CO_2

Introduction:

What are Science-based Targets? Many communities are setting ambitious climate goals, which can help to reduce greenhouse gas emissions over time. Unless these goals are grounded in scientific reality, however, we don't know whether or not they will succeed. Science-based targets take into account the overall percent of GHG emissions cuts that are needed to stabilize the global climate. Currently, the main entities setting science-based targets are states, cities, and businesses aligned with COP21. Science-based targets ensure that every partner is doing their own "fair share." Cities setting science-based targets will provide important leadership on how to let the science lead our policy to ensure success.

Some background:

Background on Dr. James Hansen – Dr. James Hansen was previously the head of NASA. He is a leading atmospheric scientist from Columbia University, and has been publishing climate projections based on complex Atmosphere-Ocean General Circulation Models (AOGCMs) for decades. He stepped down from his position at NASA because he could no longer remain non-political about climate change, and began supporting young people and other activists in their efforts to bring about action through the legal system and peaceful protest. He is the first to admit that activism is completely out of character for him, but he can't sit by and let politics trump science and his grandkids' future. More information can be found here http://www.columbia.edu/~jeh1/

Background on Our Children's Trust – Twenty-one youth from across the U.S., age 8-19, are suing the federal government in the U.S. District Court in Oregon. Their complaint asserts that the federal government has violated their generation's constitutional rights to life, liberty, and property and has failed to protect essential public trust resources. Similar cases have gone to court in every state. In Washington State, the youths secured a court order directing the state to issue a rule regulating greenhouse gas emissions by the end of 2016.

BELOW IS A QUICK OVERVIEW OF THE ATTACHED MATERIALS:

A. ***Young People's Burden***

The paper includes the latest global temperature graph, showing global surface temperature change from 1880-2015. The mean global temperature is now 1.3°C (2.3°F) above historic. The Paris Climate Accord agreed that 2°C could be a dangerous level of warming, and that 1.5°C was the preferred target.

Emissions of all three principle greenhouse gas emissions are accelerating, not declining.

The last time the Earth was this warm, sea level was 6-9 m (20-30ft.) higher than today.

**** We are at a point that negative CO_2 emissions are needed in order to return to a stable climate.** We can do this through forestry and agricultural management.

The issue of urgency - to not phase out fossil fuel emissions quickly means that young people will need to develop technologies to remove CO_2 from the atmosphere, at great cost and high uncertainty for success.

Discussion of the Federal court case currently being deliberated on the behalf of a group of young people suing for equal rights against the Obama administration and the fossil fuels industry.

B. **Video** link of Dr. Hansen and his granddaughter discussing the federal case.

C. The **Comments on the State of Washington's Clean Air Rule** included the argument that insufficient emissions standards violate the Clean Air Act's mandate to "preserve, protect, and enhance the air quality for current and future generations"

The main point in this argument that is relevant to the Ashland discussion is that significant and strong emissions rules by the state of Washington were determined to be NOT GOOD ENOUGH if they did not aim for 350ppm by 2100. The state's Clean Air

Rule would result in GHG emissions that, if met by the global community, would lead to more than 450ppm CO_2, which is scientifically documented as resulting in severe impacts to the resources that the state has a constitutional duty to protect for future generations.

The comments also address the need for emissions targets to be science-based, as anything else is arbitrary and anything less than the science-based targets mean that the state is implicitly legalizing emissions that put the public's health and water resources at serious risk. This violates the constitutional rights of young people.

They also show that atmospheric CO_2 must be reduced to 350ppm by 2100, and explain why 450ppm is not a sustainable target (it does not take into account the slow feedback mechanisms that will compound climate impacts).

They point out that the proposed Clean Air Rule by the state is illegal, because it goes against the science and reduces GHG emissions by only 1% per year, partially because it only covers 66% of the state's emissions sources. They state that the State of Washington is LEGALLY REQUIRED BY COURT ORDER to regulate transportation, infrastructure, forestry, agriculture, and consumption based emissions.

And they point out that the discount rate used to calculate cost:benefit ratios means that the health, welfare, and prosperity of adults in this generation are valued far more than the health, welfare, and prosperity of children and all future generations.

They show that the state has the legal authority and mandate to make policy changes that will results in 100% renewable energy by 2050. They provide a long list of potential policy changes and investments that would lead to success.

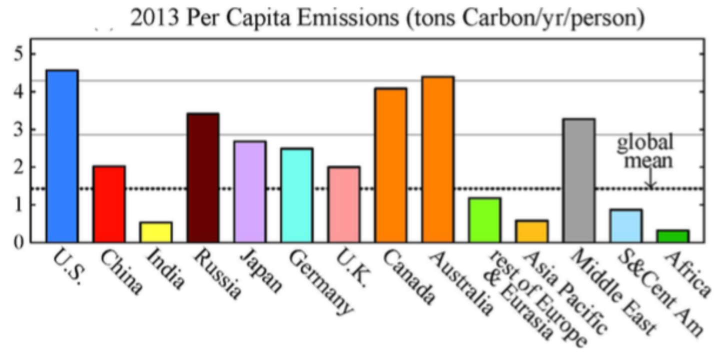
D. James Hansen's declaration in support of the Western Environmental Law Center's comments on the proposed Clean Air Rule for the state of Washington

This declaration includes the scientific basis for reducing emissions 8% per year (starting in 2017) to restore atmospheric CO_2 to 350ppm by 2100.

He states that "government actions and inactions that cause or contribute to those [GHG] emissions violate the fundamental and inalienable rights of youth and future generations. Those violated rights include the right to life, the right to liberty, the right to property, the right to equal protection under the law, the right to government protection of public trust resources, and the right to retain a fighting chance to preserve a habitable climate system."

He sites a study published in 2013 (along with 17 leading scientists)[1] that establishes the level of 350ppm atmospheric carbon as the target for avoiding “large climate change with disastrous and irreversible consequences.”

He argues that 2°C increase in temperature would lead to multi-meter sea level rise with “consequences that may threaten the very fabric of civilization.”



He shows that the U.S. has the greatest per capita emissions of all major CO2 emitting nations (which also means that we have the greatest opportunity to reduce them).

Dr. Hansen carefully outlines all of the major impacts associated with climate change, based on the best science available. He includes maps of sea level rise and discusses the uncertainty associated with ice sheet melt. He details the impacts to coral reefs, the increase in wildfires, heat waves, massive species extinctions, and ocean acidification.

And, finally, he shows how a return to 350ppm is still possible. But that each year we delay, the average annual percent reductions that are needed increase. He states “Our analysis prescribes a glide path towards achieving energy balance by the end of the century. It is characterized by large, long-term global emissions reductions (of approximately 7 percent annually if commenced this year, 8 percent if commenced in 2017, and 8.5 percent if commenced in 2018) coupled with programs to limit and reverse land use emissions via reforestation and improved agricultural and forestry practices (drawing down approximately 100 GtC globally by the year 2100).”

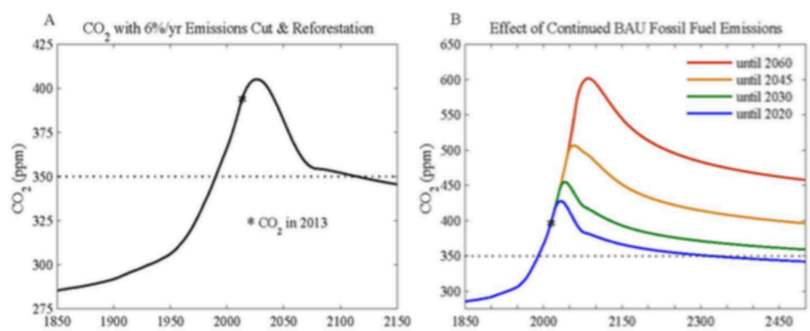


Chart 10: Atmospheric CO_2 If Fossil Fuel Emissions Are Reduced.
(A) 6% Annual Cut Begins In 2013 and 100 GRC Reforestation Drawdown Occurs In 2031-2080, (B) Effect Of Delaying Onset Of Emission Reductions.

- [1] Hansen et al. 2013. Assessing “dangerous climate change”: required reduction of carbon emissions to protect young people, future generations, and nature. PLoS One 8(12). http://dx.doi.org/10.1371/journal.pone.0081648

E. **BioScience paper on the GHG emissions associated with reservoirs, lead author** John Harrison, Associate Professor at WSU Vancouver School of the Environment. This study will be published next week, but a review is attached.

Washington State University researchers show that reservoirs emit 1.3% of all greenhouse gases produced by humans, and that they produce 25% more methane than previously thought. A growing body of work shows that reservoirs are not “green” or carbon neutral, as previously thought.

This study is relevant, as we are considering hydroelectricity as “clean” when in fact it has substantial GHG emissions associated with it. This could mean that we need even greater cuts than initially thought and might indicate that we should err on the side of more aggressive targets rather than less aggressive.

This study will need to be incorporated into the City’s GHG Inventory at a later date.

Young People's Burden

04 October 2016

James Hansen

Young People's Burden: Requirement of Negative CO_2 Emissions, by twelve of us[1], is being made available as a "Discussion" paper in ***Earth System Dynamics Discussion*** on 4 October, as it is undergoing peer review. We try to make the science transparent to non-scientists. A video discussion by my granddaughter Sophie and me is available. Here I first note a couple of our technical conclusions (but you can skip straight to "**Principal Implications**" on page 2):

1) Global temperature: the 12-month running-mean temperature is now +1.3°C relative to the 1880-1920 average in the GISTEMP analysis (Fig. 2 in above paper or alternative Fig. 1 below). We suggest that 1880-1920 is a good choice for "preindustrial" base period; alternative choices would differ by only about ±0.1°C, and 1880-1920 has the advantage of being the earliest time with reasonably global coverage and reasonably well-documented measurement technology.

Present 12-month running-mean global temperature jumps about as far above the linear trend line (Fig. 2b in the paper) as it did during the 1997-98 El Nino. The linear trend line is now at +1.06°C, which is perhaps the best temperature to compare to paleoclimate temperatures, because the latter are "centennially-smoothed," i.e., the proxy measures of ancient temperature typically have a resolution not better than 100 years. The present linear trend (or 11-year mean) temperature is appropriate for comparison to centennially smoothed paleo temperature, because we have knowledge that decadal temperature will not be declining in the next several decades.

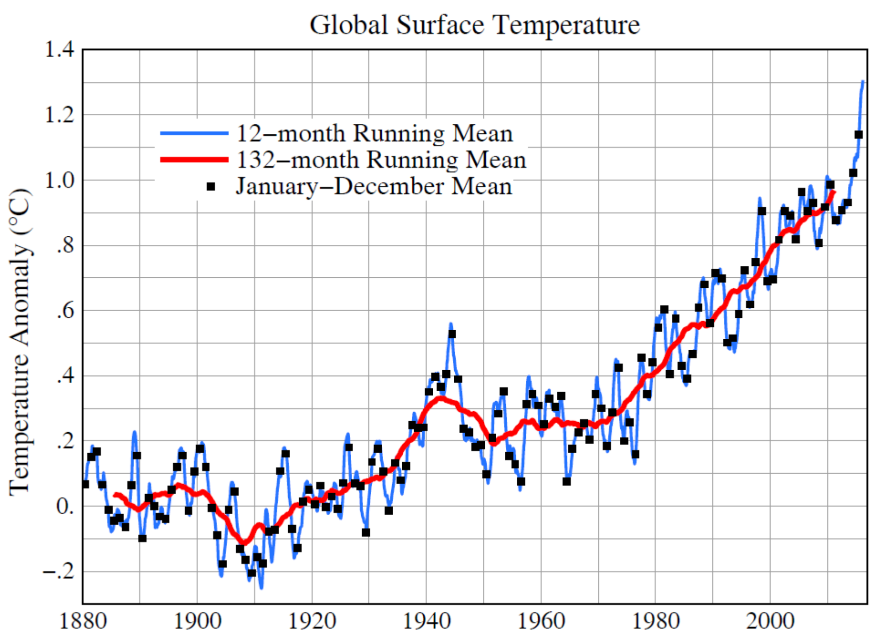


Fig. 1. Global surface temperature relative to 1880-1920 based on GISTEMP analysis (mostly NOAA data, cf. Hansen, J, R Ruedy, M Sato, and K Lo, 2010: Global surface temperature change. *Rev. Geophys.*, **48**, RG4004.

[1] J. Hansen, 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 and P. Smith

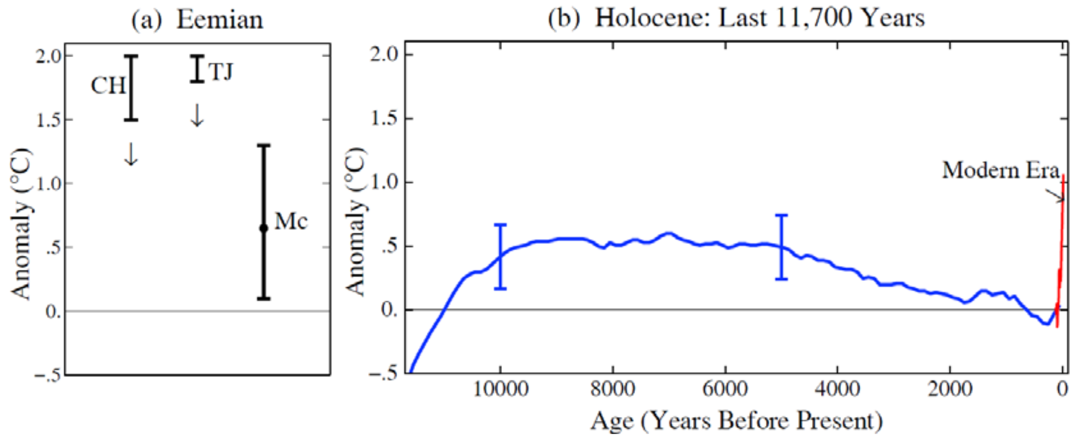


Fig. 2. Estimated average global temperature for the last interglacial (Eemian) period (McKay et al 2011; Clark and Huybers 2009; Turney and Jones 2010), the centennially-smoothed Holocene (Marcott et al 2013) temperature as a function of time, and the 11-year mean of modern data (Fig. 2). Vertical downward arrows indicate likely overestimates (see text in "Young People's Burden" paper).

2) The growth of the three principal human-caused greenhouse gases (GHGs: CO_2, CH_4, N_2O) are all accelerating. Contrary to the impression favored by governments, the corner has not been turned toward declining emissions and GHG amounts. The world is not effectively addressing the climate matter, nor does it have any plans to do so, regardless of how much government bureaucrats clap each other on the back.

On the other hand, accelerating GHG growth rates do not imply that the problem is unsolvable or that amplifying climate feedbacks are now the main source of the acceleration. Despite much (valid) concern about amplifying climate-methane feedbacks and leaks from "fracking" activity, the isotopic data suggest that the increase of CH_4 emissions is more a result of agricultural emissions. Not to say that it will be easy, but it is still possible to get future CH_4 amount to decline moderately, as we phase off fossil fuels as the principal energy source.

Principal Implications

A. Global temperature is already at the level of the Eemian period (130,000 to 115,000 years ago), when sea level was 6-9 meters (20-30 feet) higher than today (Fig. 2). Considering the additional warming "in the pipeline," due to delayed response of the climate system and the impossibility of instant replacement of fossil fuels, additional temperature rise is inevitable.

Earth's history shows that the lag of sea level change behind global temperature change is 1-4 centuries for natural climate change (Grant et al 2012, 2014)[2]. It is unlikely that response would be slower to a stronger, more rapid human-made climate forcing; indeed, Hansen et al (2016) infer that continued high fossil fuel emissions could lead to multi-meter sea level rise in 50-150 years. The desire to avoid large ice sheet shrinkage and sea level rise implies a need to get global temperature back into or close to the Holocene range on the time scale of a century or less.

B. "Negative CO_2 emissions," i.e., extraction of CO_2 from the air is now required, if climate is to be stabilized on the century time scale, as a result of past failure to reduce emissions. If rapid phasedown of fossil fuel emissions begins soon, most of the necessary CO_2 extraction can take place via improved agricultural and forestry practices, including reforestation and steps to improve soil fertility and increase its carbon content. In this case, the magnitude and duration of global temperature excursion above the natural range of the current interglacial (Holocene) could be limited and irreversible climate impacts could be minimized.

C. Continued high fossil fuel emissions place a burden on young people to undertake massive technological CO_2 extraction. Quietly, with minimal objection from the scientific community (Anderson, 2015, is a courageous exception), the assumption that young people will somehow figure out a way to undo the deeds of their forebears, has crept into and spread like a cancer through UN climate scenarios. Proposed methods of extraction such as bioenergy with carbon capture and storage (BECCS) or air capture of CO_2 imply minimal estimated costs of 104-570 trillion dollars this century, with large risks and uncertain feasibility. Continued high fossil fuel emissions unarguably sentences young people to either a massive, possibly implausible cleanup or growing deleterious climate impacts or both, scenarios that should provide incentive and obligation for governments to alter energy policies without further delay.

Personal Opinions About the Relevance of this Paper

A. The Paris Climate Accord is a precatory agreement, wishful thinking that mainly reaffirms, 23 years later, the 1992 Rio Framework Convention on Climate Change. The developing world need for abundant, affordable, reliable energy is largely ignored, even though it is a basic requirement to eliminate global poverty and war. Instead the developed world pretends to offer reparations, a vaporous $100B/year, while allowing climate impacts to grow.

B. President Obama seems not to understand that as long as fossil fuels are allowed (to appear to the user) to be the cheapest reliable energy, they will continue to be the world's largest energy source and the likelihood of disastrous consequences for young people will grow to near certainty. Obama proudly states that his EPA regulations can actually produce a greater emissions reduction than would his initial nearly-worthless proposal of a cap-and-trade "scheme". Obama salves his conscience by noting his agreement to share information with China on carbon-capture-and-storage, which neither nation will ever employ at the scale needed to deal with the climate problem, and his plans to be a climate ambassador in his old age.

C. Technically, it is still possible to solve the climate problem, but there are two essential requirements: (1) a simple across-the-board (all fossil fuels) rising carbon fee[2] collected from fossil fuel companies at the domestic source (mine or port of entry), not a carbon price "scheme," and the money must go to the public, not to government coffers, otherwise the public will not allow the fee to rise as needed for phase-over to clean energy, (2) honest government support for, rather than strangulation of, RD&D (research, development and demonstration) of clean energy technologies, including advanced generation, safe nuclear power.

D. Courts are crucial to solution of the climate problem. The climate "problem" was and is an opportunity for transformation to a clean energy future, but for the worldwide lack of

[2] Do not be misled by politicians' use of the phrase "price on carbon" or "carbon price." This is almost always a code phrase indicating they have worked out a "scheme" with special interests, or plan to work out a "scheme."

executive leadership and well-paid subservience of legislatures to the fossil fuel industry. The heavy hand of the fossil fuel industry works mostly in legal ways such as the "I'm an Energy Voter" campaign in the U.S. Failure of executive and legislative branches to deal with climate change makes it essential for courts, less subject to pressure and bribery from special financial interests, to step in and protect young people, as they did minorities in the case of civil rights.

E. "Equal Rights" and "Trust" justifications are both needed. The first lawsuit filed by Our Children's Trust against the U.S. government (Alec L et al v. Jackson et al), with science based on our Plos One paper (Hansen et al, 2013)[2] lost in the United States DC District Court, on grounds that we had not made the Constitutional basis clear enough. Our new case in the U.S. District Court in Oregon (Juliana et al v. United States) puts comparable emphasis on the "Atmospheric Trust" concept developed by Mary Wood and "Equal Rights" concept in the "Equal Protection of the Laws" and "Due Process" clauses of the U.S. Constitution.

Julia Olson, founder and leader of Our Children's Trust, gave a brilliant, compelling presentation on 13 September. Principles for the trust concept, as discussed in John Davidson's declaration that I noted earlier extend back to Greek and Roman law articulated by Cicero, through intergenerational rights and justice articulated by English theorists such as John Locke, to a concern of American Founders for "unalienable rights" of future generations, expressed in their letters, the Virginia Bill of Rights, and in our Declaration of Independence and Constitution.

Sophie, my oldest grandchild and a fellow plaintiff in the federal lawsuit, and I are especially attracted by the simple concept of equal rights, with its preeminent position in the minds of our nation's founders, the Declaration of Independence beginning "… We hold these truths to be self-evident: That all men are created equal; that they are endowed by their Creator with certain unalienable rights; that among these are life, liberty, and the pursuit of happiness;" while the Constitution begins "We the People of the United States, in order to…secure the Blessings of Liberty to ourselves and our Posterity, do ordain and establish this Constitution…". The 5th and 14th Amendments together assure equal protection of the laws and due process, people should not be deprived of life, liberty or property without due process of law. While these are U.S. centric, the Universal Declaration of Human Rights, which is generally agreed to be the foundation of international human rights law, describes similar rights.

The trust and equal rights concepts are stronger together. In some countries one or the other may be more fitting, so it is worth developing both of them.

F. Assertions and insights at the hearing.

The transcript makes clear, I believe, that the defense is grasping at straws and will fail in their effort to get the case dismissed. As just noted, however, it is important to see on what basis the case is allowed to go forward. The presiding judge, the Honorable Ann Aiken, was prepared on all arguments from both sides and provided insights about some of their flaws.

The defense argued that young people do not have standing to sue, because the government has done nothing to make them a "suspect class" that can be discriminated against. Young people are created in the usual way, and the government need not do anything to make young people and future generations different than the generation that is running the government and making decisions that can dramatically affect the former's life, liberty, property and pursuit of happiness. The older generation is now burning the fossil fuels, getting the benefits, and wittingly leaving a mess for young people to try to clean up. As Sophie says: "that's not fair." (see video)

The defense insists that the government could only be blamed for creating danger for young people if the government had taken "affirmative action" to create that danger, and, they say, the government took no affirmative action. Apparently, as Julia Olson points out, they do not want to count permits for extraction, drilling, exports and imports, transmission lines and pipelines, all to accommodate the fossil fuel energies, as part of the totality of national energy policies that the defendants are responsible for. And this is not to mention the military forces used to protect fossil fuel supply lines, most of which was never paid for, but was left as debt for young people to somehow pay for in the future, all for the benefit of the old and the problem of the young.

Judge Aiken noted the phrase "all deliberate speed," which played an important role in civil rights, a careful statement in the 1954 Brown v Board of Education decision. The Court could not meddle in the details of lawmaking and administration, but it could require that the other branches of government take actions that provide for civil rights with all deliberate speed, a phrase that was associated with the much-respected Oliver Wendell Holmes. However, after 10 years Justice Hugo Black declared in 1964 that "the time for mere 'deliberate speed' has run out," because the phrase was being used to delay compliance with the Court order.

"All deliberate speed" will be a dominant issue for climate. Our governments have not accepted the reality dictated by the laws of physics and climate science: we must phase out fossil fuel emissions rapidly. Mother Nature will not wait for bumbling half-baked government schemes for reducing emissions. It will be essential that the Court not only demand all deliberate speed, but continually examine the reality of what the government is accomplishing, and that the government have both short-term and long-term plans of action.

G. Funding for worldwide carbon sequestration and trace gas reductions.

Young People's Burden makes clear that rapid reduction of fossil fuel emissions is the most important requirement to assure prospects of young people, but it is not enough. It is also necessary to have a large drawdown of atmospheric CO_2 via improved agricultural and forestry practices, and to have multiple actions that limit the growth of or even achieve a reduction of other trace gases. These actions will need to occur nearly worldwide, especially in developing countries, and, even though there are some local benefits of many of these actions, substantial resources will be needed to see their realization.

Here is where legal action is almost surely required. Just as the tobacco industry was required to pay compensation to the public for health damage of smoking, so the fossil fuel industry should be required to pay, in view of the great largesse it has received from the public and the damage it is inflicting on young people and worldwide. Administration of these funds should be such as to continually evaluate and reward those countries that are most successful in taking the needed actions that store carbon and reduce trace gas abundances, thus avoiding graft and funds misuse.

Our Children's Trust

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July 22, 2016

Via Electronic & U.S. Mail

Sam Wilson
Department of Ecology
P.O. Box 47600, Olympia, WA 98504-7600
Email: AQComments@ecy.wa.gov

Re: Comments on Ecology's Proposed Clean Air Rule

Dear Mr. Wilson,

These comments are being submitted on behalf of our clients, Aji and Adonis Piper, Wren Wagenbach, Lara and Athena Fain, and Gabriel Mandell, the youth who took the Washington Department of Ecology ("Ecology") to court for failing to protect their fundamental constitutional rights in response to climate change in *Foster, et al. v. Ecology*. These young people secured a court order directing Ecology to promulgate a rule limiting greenhouse gas emissions in Washington by the end of 2016. These comments are also submitted on behalf of the people and organizations who believe these children have a constitutional right to a livable future, a list of whom is included as Exhibit A to these comments. Finally, these comments are submitted on behalf of all future generations and the rights and natural resources we are working hard to pass down to them, and to whom you owe a profound obligation as their fiduciary trustee.

Thank you for the opportunity to comment on Ecology's Proposed Clean Air Rule. We truly hope that you take this opportunity to promulgate a rule that is based on science, as time is running out. Our comments are supported by declarations by some of the world's most foremost climate scientists and policy experts. As we rapidly approach climate tipping points, only the current Ecology policymakers are capable of protecting the rights of these young people. They, and the world's children, are depending on you.

I. INTRODUCTION

Ecology has clear constitutional and statutory responsibilities to cap and regulate carbon dioxide emissions based upon best available science. The best way to do that is through the direct regulation of known emission sources to force polluters to implement the pollution-prevention technology that is needed to eliminate the need for the pollution in the first place. Technology-forcing serves as a bedrock principle of the federal Clean Air Act and has been described as follows:

> The idea, briefly put, is that the government can order into being technological achievements not now enjoyed by a particular industry. A policy of technology-forcing assumes that existing market forces fail to produce an appropriate level of pollution control, either because of explicit collusion among the manufacturers[1] or because of the inability of spillover victims to communicate and enforce their needs within the market. A policy of technology-forcing presupposes also that intervention by law will bring a response, either from the manufacturers themselves or equipment suppliers, and that these new forces can be loosed to create a technology that is "superior" to the ones it replaces. The metaphors of this movement are of reluctance overcome, of fires being lit, of perceived limits quickly surpassed, of wills and ways.[2]

Ecology's proposed Clean Air Rule, as it is currently structured, serves to undercut technological solutions to climate change. A cap and trade system, if it is to be used at all, should be the cherry on top of a powerful regulatory scheme mandating the reduction, and ultimate elimination, of carbon dioxide emissions. Cap and trade can potentially be one tool to make a scientifically-targeted regulatory program more palatable for those corporations who put profits before the health and wellbeing of their children and future generations. However, it should not be used as the centerpiece of a regulatory plan that exempts, excuses and makes allowances for not reducing emissions that can technically, economically and feasibly be reduced to protect life, liberty, and all of the fundamental rights of citizens, especially Washington youth and future generations.

These comments set forth both a specific critique of the proposed Clean Air Rule and identifies alternative regulatory mechanisms that Ecology has the existing authority to promulgate and implement. As you know, in June 2014, youth submitted a Petition for Rulemaking with the Department of Ecology asking the agency to use its existing authority to cap and regulate GHG emissions based upon best available science. Two years later, we are saddened and frustrated that Ecology continues to ignore the scientific consensus on what needs to be done to stem the tide of climate change. Ecology, as the legislatively designated trustee of the natural resources of Washington, must adopt a rule to achieve science-based emission reductions necessary to do Washington's part to stabilize the climate and protect our oceans.

II. <u>THE PROPOSED RULE DOES NOT COMPLY WITH THE COURT ORDER IN *FOSTER , ET AL. v. ECOLOGY*</u>

On June 24, 2014, eight young Washingtonians filed a petition for rulemaking with Ecology, asking that the agency use its existing legal authority to (1) promulgate a

[1] Indeed, the Clean Air Act was largely passed in response to the "smog conspiracy," whereby automobile manufacturers conspired to retard the development of pollution prevention control technology.
[2] Rodgers, 1 Environmental Law at § 3.25(A).

rule mandating reductions of greenhouse gases ("GHGs") based upon the most current climate science; and (2) and make its statutorily-required recommendation to the legislature on adjusting GHG emission limits (RCW 70.235.040) based on current science through rulemaking.[3] On August 14, 2014, Ecology denied Youth Petitioners' Petition for Rulemaking.[4] Without addressing the scientific basis for the proposed rule, or its legal responsibility to manage essential natural resources such as air and water, the agency summarily denied the petition for three reasons: (1) nothing in RCW 70.235 requires Ecology to adopt different emissions reductions, develop a plan to ensure those reductions, or implement the monitoring requirements in the proposed rule; (2) Washington "is working to achieve the reductions" set forth in RCW 70.235 and "the measures it is taking are an alternative approach to your proposed rule;" and (3) none of the additional cited sources in the petition require Ecology to adopt the proposed rule.[5] After over a year of litigation, on November 19, 2015 the Court issued a landmark decision outlining Ecology's legal responsibilities to take immediate action to address climate change.[6] At that time, the Court did not order Ecology to undertake rulemaking as Governor Inslee had directed Ecology to do so in July 2015, shortly after meeting with the youth petitioners to discuss the case.

After Ecology withdrew the proposed Clean Air Rule in February 2016, the youth went back to Court, this time securing a court order directing Ecology to do two things: "(1) Ecology shall proceed with the rulemaking procedure to adopt a rule to limit greenhouse gas emissions in Washington state as directed by Governor Inslee in July 2015, and shall issue the rule by the end of calendar year 2016; (2) Ecology shall provide a recommendation to the 2017 legislature on greenhouse gas limits for the state of Washington as provided in RCW 70.235.040."[7] When exercising its authority to promulgate a rule regulating carbon dioxide emissions as mandated by Court order, Ecology has a responsibility to fulfill its legal obligations as interpreted by Judge Hill in the *Foster* case.

a. <u>Ecology's Existing Efforts Are Inadequate</u>

Importantly, in the *Foster* case, the Court found that Ecology's "alternative approach" to dealing with climate change was legally insufficient. Specifically:

> the emission standards currently adopted by Ecology do not fulfill the mandate to '[p]reserve, protect and enhance the air quality for current and future generations.' The regulations currently in place specify technological controls of a small number of air pollution sources while not even addressing transportation which as of 2010 was responsible for 44% of annual total GHG emissions in Washington State. *One need*

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[3] Petition for Rulemaking (June 17, 2014) (Exhibit B).
[4] Ecology's Denial (August 14, 2014) (Exhibit C).
[5] *Id.* at 1.
[6] *Foster, et al. v. Ecology*, No. 14-2-25295-1 SEA (King County Superior Court) (Order Affirming the Department of Ecology's Denial of Petition for Rulemaking) (Nov. 19, 2015) (Exhibit D).
[7] *Foster, et al. v. Ecology*, No. 14-2-25295-1 SEA (King County Superior Court) (Order on Petitioners' Motion for Relief Under CR 60(b)) (May 16, 2016) (Exhibit E).

> *only go back to Ecology's pronouncement in the December 2014 report to appreciate the inadequacy of its current efforts to preserve, protect and enhance the air quality for current and future generations*.[8]

In rendering her decision, the Court made it clear that Ecology needed to undertake additional actions to protect the fundamental rights of the youth petitioners:

> In fact, as Petitioners assert and this court finds, their very survival depends upon the will of their elders to act now, decisively and unequivocally, to stem the tide of global warming by accelerating the reduction of emission of GHG's before doing so becomes first too costly and then too late. The scientific evidence is clear that the current rates of reduction mandated by Washington law cannot achieve the GHG reductions necessary to protect our environment and to ensure the survival of an environment in which Petitioners can grow to adulthood safely. In fact, in its 2014 report to the legislature, the Department stated, "Washington's existing statutory limits should be adjusted to better reflect the current science. The limits need to be more aggressive in order for Washington to do its part to address climate risks . . . ."[9]

The Court's findings regarding the inadequacy of Ecology's current approach to climate change is pertinent as it highlights where Ecology must focus its efforts when regulating carbon dioxide emissions.

b. <u>Ecology Has A Mandatory, Statutory Duty To Protect Air Quality for Current & Future Generations Under the WA Clean Air Act</u>

The Court found that Ecology "does have the mandatory duty under the Clean Air Act to '[a]dopt rules establishing air quality standards' for GHG emissions, including carbon dioxide that 'shall constitute minimum emissions standards throughout the state.' RCW 70.94.331(2)(a)(b). *This obligation must be implemented in a manner that '[p]reserves, protect[s] and enhance[s] the air quality for the current and future generations.'* RCW 70.94.011."[10] The draft Clean Air Rule violates the plain language of the Clean Air Act as it will not "preserve, protect, and enhance the air quality for current and future generations."[11] Furthermore, the draft Clean Air Rule violates the Legislature's express purpose for adopting the Clean Air Act. The Legislature has found that:

> Air is an essential resource that must be protected from harmful levels of pollution. Improving air quality is a matter of statewide concern and is in

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[8] *Foster, et al. v. Ecology*, No. 14-2-25295-1 SEA (King County Superior Court) (Order Affirming the Department of Ecology's Denial of Petition for Rulemaking) (Nov. 19, 2015) at 6 (emphasis added) (Exhibit D).
[9] *Id*. at 5.
[10] *Id*. at 6 (emphasis added).
[11] RCW 70.94.011.

> the public interest. It is the intent of this chapter to secure and maintain levels of air quality that protect human health and safety, including the most sensitive members of the population, to comply with the requirements of the federal clean air act, to prevent injury to plant, animal life, and property, to foster the comfort and convenience of Washington's inhabitants, to promote the economic and social development of the state, and to facilitate the enjoyment of the natural attractions of the state.
>
> It is further the intent of this chapter to protect the public welfare, to preserve visibility, to protect scenic, aesthetic, historic, and cultural values, and to prevent air pollution problems that interfere with the enjoyment of life, property, or natural attractions.[12]

These are not merely words on paper. When Ecology implements its delegated authority to "adopt rules establishing air quality objectives and air quality standards" and "adopt emission standards which shall constitute minimum emission standards throughout the state,"[13] it must do so in a manner that fulfills the legislative intent as expressed in RCW 70.94.011. The draft Clean Air Rule fails to do so.

c. <u>Ecology Has A Constitutional Duty to Protect Public Trust Resources</u>

The Court held that "Washington courts have found that this provision [WA Const. Art. XVII, Sec. 1] requires the State through its various administrative agencies, to protect trust resources under their administrative jurisdiction."[14] "Therefore, the State has a constitutional obligation to protect the public's interest in natural resources held in trust for the common benefit of the people of the State."[15] The Court recognized the scientific reality that "[t]he navigable waters and the atmosphere are intertwined and to argue a separation of the two, or to argue that GHG emissions do not affect navigable waters is nonsensical. Therefore, the Public Trust Doctrine mandates that the State act through its designated agency to protect what it holds in trust. The Department of Ecology is the agency authorized both to recommend changes in statutory emission standards and to establish limits that are responsible."[16]

Ecology continues to ignore the fact that it has a constitutional duty to protect Public Trust Resources in the state. The draft Clean Air Rule will not protect public trust resources within Ecology's jurisdiction such as air, tidelands, shorelands, and water.

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[12] RCW 70.94.011.
[13] RCW 70.94.331(1), (2).
[14] *Id*. at 7.
[15] *Id.*at 8.
[16] *Id.*

d. The Youth Have Fundamental & Inalienable Rights to Live in a Healthful & Pleasant Environment

Most significantly, the Court acknowledged that "Ecology's enabling statute states, "'[I]t is a fundamental and alienable right of the people of the State of Washington to live in a healthful and pleasant environment.' RCW 43.21A.010. Although courts have stated that a statutory duty cannot be created merely from the words of the enabling statute, this language [in RCW 43.21A.010] does evidence the legislature's view as to rights retained under Article I, Section 30" of the Washington Constitution.[17] In light of those fundamental legal rights,

> If ever there were a time to recognize through action this right to preservation of a healthful and pleasant atmosphere, the time is now as: 'Climate change is not a far off risk. It is happening now globally and the impacts are worse then previously predicted, and are forecast to worsen . . . If we delay action by even a few years, the rate of reduction needed to stabilize the global climate would be beyond anything achieved historically and would be more costly.'[18]

Ecology is legally obligated to promulgate a rule that complies with the Court's prior interpretations of the law in the *Foster* case, as that is the controlling precedent. Unfortunately, for the reasons set forth below, Ecology's proposed Clean Air Rule does not come close to satisfying the law as specified in Judge Hill's order, including Ecology's statutory, constitutional and public trust obligations. Ecology is legally and morally obligated to create a statewide Climate Action Plan that protects the fundamental constitutional rights of young people in this state.

III. ECOLOGY HAS THE LEGAL AUTHORITY & DUTY TO PROMULGATE SCIENCE-BASED EMISSION LIMITS

As described above, Judge Hill clearly laid out the constitutional and statutory framework for Ecology to promulgate a rule that fulfills its legal obligations while protecting the rights of young people and future generations. In addition, Ecology has other sources of authority that can and should be invoked in developing a true Climate Action Plan based upon science. Climate change is an "all hands on deck" issue that requires Ecology to implement the full panoply of their legal authority.

a. Ecology Must Do Its Part To Reach Global Climate Stabilization Levels

RCW 70.235.020 sets the following *floor* for GHG emission reductions:

(i) By 2020, reduce overall emissions of greenhouse gases in the state to 1990 levels.

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[17] *Id*. at 9.

[18] *Id.* (quoting Ecology, Washington Greenhouse Gas Emissions Reduction Limits, Prepared Under RCW 70.235.040 (Dec. 2014) (Exhibit G)).

(ii) By 2035, reduce overall emissions of greenhouse gases in the state to twenty-five percent below 1990 levels;

(iii) By 2050, the state will do its part to reach global climate stabilization levels by reducing overall emissions to fifty percent below 1990 levels, or seventy percent below the state's expected emissions that year.

Ecology has correctly noted that this statute reflects "the Legislature's intent to reduce GHG emissions," but improperly views the statutory emission limits as a constraint on its authority to establish science-based GHG emissions limits.[19] The AG has interpreted this statute as suggesting that "the legislature intended the reductions goals to be taken seriously . . . ."[20] *RCW 70.235 does not in any way limit Ecology's authority to promulgate a science-based rule; indeed, the statute only sets a floor for GHG emission limits and does not preclude Ecology from recommending more stringent limits pursuant to its existing statutory authority and constitutional obligations.*[21] It would be illogical to interpret RCW 70.235 as the most stringent emission limits that Ecology can adopt. For example, would Ecology be in violation of the statute if it were to achieve emissions reductions of 26% below 1990 levels by 2035, instead of 25%? This would be an absurd result.[22] What is clear from the plain language of RCW 70.235.020 is the legislature's intent that Washington base its efforts on the best available climate science and "do its part to reach global climate stabilization levels," which the current scientific evidence demonstrates is global atmospheric concentrations of 350 ppm by the end of the century, a standard never disputed by Ecology.

When the statute is read in its entirety, it is clear that Ecology is not constrained by the emission targets based in RCW 70.235.020. Indeed, the State's GHG reduction statute imposes the following mandatory duty on Ecology:

> Within eighteen months of the next and each successive global or national assessment of climate change science, the department shall consult with the climate impacts group at the University of Washington regarding the science on human-caused climate change and provide a report to the legislature summarizing that science and make recommendations regarding whether the greenhouse gas emissions reductions required under RCW 70.235.020 need

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[19] Ecology, SEPA Environmental Checklist – Clean Air Rule, Appendix A, Staff Report – SEPA Non-Project Review Form, Proposed Clean Air Rule (May 2016) at 5.

[20] Attorney General Opinion to Senator Doug Ericksen (Sept. 1, 2015) at 2.

[21] While we do not necessarily agree with the interpretation of RCW 70.235 by the Attorney General's Office, it has taken the position that RCW 70.235 is not enforceable, nor binding on the State. Thus, whether our legal interpretation is correct or Ecology follows the advice of the Attorney General, the statute does not pose any barrier to Ecology's ability to fully implement its statutory, constitutional, and public trust mandate. *Id*. at 1 (finding that the emission "reductions are not a ministerial duty of any specific state official.").

[22] *See Tingley v. Haisch*, 159 Wn.2d 652, 664, 152 P.3d 1020 (2007) (quoting *State v. J.P.*, 149 Wn.2d 444, 450, 69 P.3d 318 (2003) ("A reading [of a statute] that produces absurd results must be avoided because 'it will not be presumed that the legislature intended absurd results.'") (internal quotations omitted)).

to be updated.[23]

This language makes it clear that the legislature intended the limits be based upon the most current climate science. After Governor Inslee directed Ecology to make this recommendation to the legislature by July 15, 2014,[24] the Youth Petitioners asked Ecology to make its recommendations to the Legislature through the rulemaking process because "Ecology's legislative recommendations implicate youth petitioners' and future generations' rights to essential public trust resources . . . ."[25] It has been over eight years since RCW 70.235 was enacted, and Ecology has still not made a recommendation to the legislature to update the reductions in RCW 70.235.020, despite several advances in the climate science. This failure is fatal to the development of the Clean Air Rule as it is impossible for Ecology to target its reductions in a fashion that protects the rights of young people and future generations, if it continues to refuse to tell the public what those targets should be.

Ecology's independent decision to target the Clean Air Rule to the emissions limits in RCW 70.235, rather than the best science, is arbitrary in light of the fact that Ecology has concluded that "Washington State's existing statutory limits should be adjusted to better reflect the current science" and that "[t]he limits need to be more aggressive in order for Washington to do its part to address climate risks and to align our limits with other jurisdictions that are taking responsibility to address these risks."[26] Ecology's continued failure to make a substantive "recommendation" to the Legislature to update RCW 70.235.020 based upon current climate science serves to exacerbate, prolong, and potentially ensure perpetually the impairment of Youth Petitioners' fundamental and inherent rights to a healthful and pleasant environment.[27] Not only is Ecology failing to take legally required action,[28] but the agency is affirmatively advocating, by virtue of its silence, that the Washington Legislature "impos[e] risks on future generations (causing intergenerational inequities) and liability for the harm that will be caused by climate change that we are unable or unwilling to avoid."[29] In light of the clear threats to Youth Petitioners' inalienable rights to a healthful and pleasant environment, Ecology's decision to target the Clean Air Rule to RCW 70.235.020 is irrational and will not be upheld by a

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[23] RCW 70.235.040.
[24] Washington Executive Order 14-04 (April 29, 2014) (Exhibit F).
[25] Youth Petition for Rulemaking (June 17, 2014) (Exhibit B) at 53.
[26] Ecology December 2014 Report (Exhibit G) at 18. Ecology's action essentially asks the Legislature to violate the Public Trust Doctrine which "prohibits the State from disposing of its interest in the waters of the state in such a way that the public's right of access is substantially impaired, unless the action promotes the overall interests of the public." *Rettkowski*, 122 Wn.2d at 232.
[27] Ecology December 2014 Report (Exhibit G) at 15 ("Globally, 2013 was the fourth warmest year on record. Globally averaged temperature has increased by 1.5° or 0.85°C between 1880 and 2012. The [IPCC] confirmed continuing the current pattern of greenhouse gas emissions would likely lead to a rise in temperature which will pose unprecedented risks to people's lives and wellbeing.").
[28] Ecology is now court ordered to make the recommendation to the legislature in advance of the 2017 legislative session. *Foster et al. v. Ecology*, No. 14-2-25295-1, King County Superior Court (Order on Petitioners' Motion for Relief Under CR 60(b)) (May 16, 2016) (Exhibit E) at 3 ("Ecology shall provide a recommendation to the 2017 legislature on greenhouse gas limits for the state of Washington as provided in RCW 70.235.040.").
[29] *Id.* at 18.

court of law.

Furthermore, Ecology's claims that "[t]he proposed rule is intended to at a minimum achieve the statutory reductions in Chapter 70.235 RCW," is contradicted by information in the rulemaking record.[30]

It makes no sense for Ecology to promulgate a Clean Air Rule in advance of making its recommendation to the Legislature to revise the emission reductions in RCW 70.235.020. The science is clear as to what those reductions need to be, but Ecology continues to abdicate its moral and legal responsibility to tell Washingtonians how we collectively must reduce our GHG emissions to "do [our] part to reach global climate stabilization levels."[31] Because Ecology is now court-ordered to make this legislative recommendation, it is imperative that Ecology target its Clean Air Rule towards achieving the science-based emission reductions contained in its recommendation, not the reductions set forth in RCW 70.235.020, which the agency acknowledge would lead to dangerous levels of warming and would jeopardize the rights of young people.

b. Ecology Must Use Its Authority To Protect Public Health

Ecology's proposed rule permits GHG emissions beyond levels that are safe for humanity. By legalizing emissions at dangerous levels, Ecology places the public's health at serious risk. As discussed above, Ecology is bound by law to "preserve, protect, and enhance the air quality for current and future generations."[32] Ecology's authority under the Washington Clean Air Act is quite broad. Under the law, the Legislature directs Ecology to "secure and maintain levels of air quality that protect human health and safety."[33] Furthermore, this protection is extended to plants, animals, and property.[34] Recognizing the serious consequences of air pollution in Washington, the Legislature called for immediate action to return air quality levels to "protect health and the environment" and to "prevent any areas of the state with acceptable air quality from reaching air contaminant levels that are not protective of human health and the environment."[35]

Human-caused fossil fuel burning and the resulting climate change are already contributing to an increase in asthma, cancer, cardiovascular disease, stroke, heat-related morbidity and mortality, food-borne diseases, and neurological diseases and disorders.[36] Climate change has been called "the most serious threat to the public health of the 21st

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[30] Ecology, Cost Benefit Analysis at 51.
[31] RCW 70.235.020(1)(a)(iii).
[32] RCW § 70.94.011.
[33] *Id.*
[34] *Id.*
[35] *Id.*
[36] *See* The Center for Health and the Global Environment, Harvard Medical School, *Climate Change Futures: Health, Ecological, and Economic Dimensions* (Nov. 2005), http://coralreef.noaa.gov/aboutcrcp/strategy/reprioritization/wgroups/resources/climate/resources/cc_futures.pdf; USGCRP, *Climate Change Impacts*, *supra* note 102, at 221-28.

century."[37] Droughts, floods, heat waves and other extreme weather events linked to climate change also lead to a myriad of health issues.[38] The World Health Organization has stated that "[l]ong-term climate change threatens to exacerbate today's problems while undermining tomorrow's health systems, infrastructure, social protection systems, and supplies of food, water, and other ecosystem products and services that are vital for human health."[39] Climate change is not only expected to affect the basic requirements for maintaining health (clean air and water, sufficient food, and adequate shelter) but is likely to present new challenges for controlling infectious disease and even "halt or reverse the progress that the global public health community is now making against many of these diseases."[40] Children are especially vulnerable to adverse health impacts due to climate change.

Recent studies have highlighted the adverse mental health effects that result from climate change. One study noted that as many as 200 million Americans are expected to have mental health problems as a result of climate change impacts and added that mental health disorders are likely to be one of the most dangerous indirect health effects of climate change. The mental health effects can include elevated levels of anxiety, depression, PTSD, and a distressing sense of loss. The impacts of these mental health effects include chronic depression, increased incidences of suicide, substance abuse, and greater social disruptions like increased violence.[41]

In Washington, most health effects associated with climate change are expected to be negative and will include increased respiratory diseases, including asthma, heart attacks, and cancer.[42] Moreover, as GHG emissions stay the same and continue to rise, Washingtonians can expect increased water shortages due to decreased snowpack and early snowmelt.[43] Water shortages affect the viability of native salmon species, which jeopardizes the mental health and welfare of the state's tribal communities, who have relied upon these natural resources for time immemorial.

By authorizing the State's top polluters to continue unsafe levels of GHG emissions that exceed both scientific and end existing statutory limits, Ecology actively puts Washingtonians' health at risk, in violation of Ecology's mandate under the Clean Air Act. The People entrusted Ecology to protect them from the harmful effects of air pollution and climate change. By allowing industry to continue to pollute beyond safe limits, the department breaches this trust.

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[37] Casey Crandell, *Climate Action Holds Potential for Massive Improvements in Public Health,* Physicians for Social Responsibility (June 22, 2015), http://www.psr.org/blog/climate-action-holds-potential-improvements-public-health.html.

[38] *Id.*

[39] World Health Organization, *Atlas of Health and Climate* 4 (Oct. 2012), http://www.who.int/globalchange/publications/atlas/report/en/.

[40] World Health Organization, *Protecting Health from Climate Change: Connecting Science, Policy, and People* 2 (2009), http://www.who.int/globalchange/publications/reports/9789241598880/en/index.html.

[41] Nick Watts et al., *Health and Climate Change: Policy Responses to Protect Public Health*, The Lancet (June 23, 2015), http://www.thelancet.com/commissions/climate-change-2015.

[42] *See* Devra R. Cohen, *Forever Evergreen: Amending the Washington State Constitution for a Healthy Environment*, 90 Wash. L. Rev. (2015) 349, 391.

[43] *Id.*

c. The Clean Air Rule Must Protect the Waters of the State

By not developing a rule that is based on science and targeted to put Washington on a path to reaching global climate stabilization levels, Ecology is abdicating its responsibility as trustee of the waters of the state. The legislature has delegated a significant amount of authority to Ecology to act to protect the natural resources in the state, including air and water. In passing the Clean Air Act, the legislature explicitly recognized "air pollution control projects may affect other environmental media. In selecting air pollution control strategies state and local agencies shall support those strategies that lessen the negative environmental impact of the project on all environmental media, including air, water, and land."[44] Ecology can and should implement this authority to fulfill its statutory mandate to protect both the air and waters of the state:

> it is the purpose of this chapter to establish a single state agency with the authority *to manage and develop our air and water resources in an orderly, efficient, and effective manner and to carry out a coordinated program of pollution control involving these and related land resources.* To this end a department of ecology is created by this chapter to undertake, in an integrated manner, the various water regulation, management, planning and development programs now authorized to be performed by the department of water resources and the water pollution control commission, the air regulation and management program now performed by the state air pollution control board, the solid waste regulation and management program authorized to be performed by state government as provided by chapter 70.95 RCW, and such other environmental, management protection and development programs as may be authorized by the legislature.[45]

"The legislature further recognizes that as the population of our state grows, the need to provide for our increasing industrial, agricultural, residential, social, recreational, economic and other needs will place an increasing responsibility on all segments of our society to plan, coordinate, restore and regulate the utilization of our natural resources in a manner that will protect and conserve our clean air, *our pure and abundant waters,* and the natural beauty of the state."[46]

Ecology is specifically charged with "the supervision of public waters within the state."[47] "[A]ll waters within the state belong to the public" and "[t]he power of the state to regulate and control the waters within the state shall be exercised" in accordance with

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[44] RCW 70.94.011.
[45] RCW 43.21A.020 (emphasis added).
[46] RCW 43.21A.010 (emphasis added).
[47] RCW 43.21A.064(1).

RCW 90.03.[48] Only Ecology has the authority to establish and protect minimum flows or levels.[49] Only Ecology has "the jurisdiction to control and prevent the pollution of streams, lakes, rivers, ponds, inland waters, salt waters, water courses, and other surface and underground waters of the state of Washington."[50] As part of that authority, Ecology has a mandatory duty to promulgate "rules and regulations relating to standards of quality for waters of the state and for substances discharged therein in order to maintain the highest possible standards of all waters of the state in accordance with the public policy as declared in RCW 90.48.010."[51] Given the devastating impacts our waters are, and will be, facing due to climate change, it is imperative that Ecology invoke its statutory authority as trustee of our state's water resources and promulgate a Clean Air Rule that is based on science.

d. The Clean Air Rule Must Mitigate Against Ocean Acidification

Ecology has recognized that global warming is occurring and adversely impacting Earth's climate.[52] At the same time, ocean acidification "has been observed," due to the ocean absorbing approximately "30 percent of the emitted anthropogenic carbon dioxide," thereby threatening Earth's ocean life.[53] If immediate action is not taken to draw down carbon dioxide emissions, the costs of climate change and ocean acidification impacts to Washington are projected at $10 billion per year by 2020.[54]

As discussed above, Ecology is the agency with the authority to adopt "rules and regulations relating to standards of quality for waters of the state and for substances discharged therein in order to maintain the highest possible standards of all waters of the state in accordance with the public policy as declared in RCW 90.48.010."[55] The State has previously acknowledged, "acidification near the coasts, and particularly in highly populated and developed areas, is often exacerbated by local sources of pollutants, such as nutrients and organic material, that generate additional carbon dioxide in marine waters."[56] In spite of long-standing efforts by the Center for Biological Diversity,[57] Ecology still has not amended its water quality standards or taken other regulatory action

[48] RCW 90.03.010.
[49] RCW 90.03.247; RCW 90.22.010 ("The department of ecology may establish minimum water flows or levels for streams, lakes or other public waters for the purposes of protecting fish, game, birds or other wildlife resources, or recreational or aesthetic values of said public waters whenever it appears to be in the public interest to establish the same.").
[50] RCW 90.48.030.
[51] RCW 90.48.035.
[52] *Foster, et al. v. Ecology*, King County Superior Court No. 14-2-25295-1 SEA (Ecology's Answer) (filed October 6, 2014) at 3:3-5.
[53] *Id.* at 3:4, 14-16.
[54] Washington Executive Order 14-04 (April 29, 2014).
[55] RCW 90.48.035.
[56] Washington Executive Order 12-07 (November 27, 2012).
[57] The legal authority and obligation to use existing authority to address ocean acidification is set forth in the attached petitions, both of which are hereby incorporated by reference. Center for Biological Diversity, Petition to EPA for Additional Water Quality Criteria & Guidance Under Section 304 of the Clean Water Act, 33 U.S.C. § 1314, to Address Ocean Acidification (April 17, 2013) (Exhibit H); Center for Biological Diversity Petition to EPA for Revised State Water Quality Standards for Marine pH Under the Clean Water Act, 33 U.S.C. § 1313(c)(4) (October 18, 2012) (Exhibit I).

to address ocean acidification. This should be done forthwith and is an integral component of any attempt by Ecology to address climate change.

IV. THE PROPOSED CLEAN AIR RULE VIOLATES ECOLOGY'S STATUTORY & CONSTITUTIONAL OBLIGATIONS BECAUSE IT LEGALIZES DANGEROUS LEVELS OF GHG EMISSIONS & FAILS TO UTILIZE CURENT CLIMATE SCIENCE

The draft Clean Air Rule violates Ecology's constitutional and statutory responsibilities as outlined above because it legalizes dangerous levels of carbon dioxide emissions. No person or corporation has the legal right to emit unlimited amounts of carbon dioxide in a manner that abridges the constitutional rights of young people and violates the existing statutory laws. Ecology's historic inability to regulate emissions of carbon dioxide does not somehow confer upon an entity the right to continue to pollute, because that right never existed. By promulgating a Clean Air Rule that regulates only a very small segment of entities that emit GHG gases over a certain threshold (beginning at 100,000 metric tons of CO2e starting in 2017, and leading to 70,000 metric tons of CO2e in 2035), Ecology has implicitly authorized continued emission of GHGs by all entities that fall under those thresholds, including non-covered entities. Ecology is without authority to do so because the science is clear that action violates the constitutional rights of young people.

a. Ecology Must Base Its Rule On The Best Available Climate Science to Protect Young People & Future Generations

i. The Best Available Climate Science Provides a Prescription for Restoring the Atmosphere, Stabilizing the Climate System & Protecting the Waters of the State: Atmospheric CO2 Levels Must Be Reduced to Below 350 ppm By 2100

In order to protect our planet's climate system and vital natural resources on which human survival and welfare depends, and to ensure that young people's and future generations' fundamental and inalienable human rights are protected, the Clean Air Rule *must* be based on the best available climate science. There are numerous scientific bases for setting 350 parts per million ("ppm") as the uppermost safe limit for atmospheric CO_2 concentrations. Ecology continues to shirk its responsibility to inform the public what GHG emissions are necessary to fulfill its constitutional and statutory obligations. Notably, the agency has presented no science that contradicts this scientific prescription first presented by youth in Washington State in 2011.[58]

There are three main reasons why Ecology must adopt the scientific prescription described in these comments. First, returning CO_2 concentrations to 350 ppm would restore the energy balance of Earth and allow as much heat to escape into

[58] *Svitak, et al. v. State*, King County Superior Court No. 11-2-16008-4 SEA (Amended Complaint) (filed May 18, 2011) (Exhibit J).

space as Earth retains, which has kept our planet in the "sweet spot" for humans and other species to thrive.

Second, CO_2 levels exceeding 350 ppm are creating a planet warmer than humans have ever lived in and are disrupting the physical and biological systems in which human civilization has evolved. The consequences of even 1 degree Celsius of warming will be significant for humanity, but scientists believe we can preserve our ice sheets and for the most part our shorelines and ecosystems, if we limit long-term warming to 1 degree Celsius (short-term warming will inevitably exceed 1 degree Celsius but must exceed 1 degree Celsius for a minimal amount of time). If we allow sustained global average temperature increases of more than 1 degree Celsius we will suffer irreversible climate destabilization and a planet largely inhospitable to human civilization.

Third, marine animals, including coral reefs, cannot tolerate the acidifying and warming of our ocean waters that results from increased CO_2 levels, 30% of which is absorbed by the oceans. At 400 ppm CO_2, the coral reefs of the world and shellfish are rapidly declining and will be irreversibly compromised if we do not quickly reverse course. The economic and cultural consequences of the loss of marine resources, including salmon and shellfish, are exponential and cannot be quantified.

All government policies, including the Clean Air Rule promulgated by Ecology, regarding greenhouse gas/CO_2 pollution and de/reforestation worldwide should be aimed at 350 ppm by 2100. Fortunately, it is still not only technically and economically feasible to get there, but transitioning to renewable energy sources will provide significant economic and public health benefits and improve the quality of lives. But time is running out. We cannot continue to base life and death policies on politics rather than science.

1. Restoration of the Earth's Energy Balance

To protect Earth's climate for present and future generations, we must restore Earth's energy balance. By burning fossil fuels and deforesting the planet,[59] which results in an increase in greenhouse gases in the atmosphere, especially CO_2, humans have altered Earth's energy balance.[60] The best climate science shows that if the planet once again sends as much energy into space as it absorbs from the sun, this will restore the planet's climate equilibrium.[61] Scientists have accurately calculated how Earth's energy balance will change if we reduce long-lived greenhouse gases

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[59] Intergovernmental Panel on Climate Change, *Summary for Policymakers, Climate Change 2014: Impacts, Adaptation, and Vulnerability* 5 (2014).

[60] James Hansen et al., *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, PLOS ONE 8:12, 3763 (2013) ("Assessing *Dangerous Climate Change*").

[61] John Abatzoglou et al., *A Primer on Global Climate Change and Its Likely Impacts, in Climate Change: What It Means for Us, Our Children, and Our Grandchildren* 11, 15-22 (Joseph F. C. DiMento & Pamela Doughman eds., 2007).

such as CO_2.[62] We would need to reduce atmospheric CO_2 concentrations by at least 50 ppm, from their 2015 level of 400 ppm in order to increase Earth's heat radiation to space, if other long-lived gases do not continue to increase.[63]

2. Stop Global Surface Warming that Will Disrupt the Physical and Biological Systems on Which Humans Depend

In order to protect the physical and biological systems on which humans rely for their basic needs and the stability of their communities, we must reduce atmospheric CO_2 concentration to no more than 350 ppm and stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[64]

Current science shows that while global surface heating may rise as much as 1.5 °C above pre-industrial temperatures because of warming already locked into the pipeline from existing CO_2 pollution, to protect Earth's natural systems, long-term average global surface heating should not exceed 1°C this century. In other words, even 1.5 °C of heating is unsafe, and we must stabilize at no more than 1°C of heating over pre-industrial temperatures. *According to current climate science, to prevent global heating greater than 1°C, concentrations of atmospheric CO_2 must decline to 350 ppm or less by the end of this century*.[65] However, today's atmospheric CO_2 levels are over 400 ppm and rising.[66]

3. Targeting Reductions to Allow More than 2° Warming is Unlawful

A target of keeping global surface heating to 2°C above pre-industrial temperatures, which approximately equates to an atmospheric CO_2 concentration of 450 ppm, cannot be considered a safe target for present or future generations, and is not supported by current science of climate stabilization or ocean protection, nor is it accepted by the IPCC.[67] Notably, Ecology has admitted that "the Washington state

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[62] James Hansen, Storms of My Grandchildren 166 (2009) ("Also our best current estimate for the planet's mean energy imbalance over the past decade, thus averaged over the solar cycle, is about +0.5 watt per square meter. Reducing carbon dioxide to 350 ppm would increase emission to space 0.5 watt per square meter, restoring the planet's energy balance, to first approximation.").

[63] James Hansen, Storms of My Grandchildren 166 (2009); *see also* James E. Hansen et al., *Target Atmospheric CO_2: Where Should Humanity Aim?* 2 The Open Atmospheric Science Journal 217, 217-31 (2008), http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf [hereinafter *Where Should Humanity Aim?*].

[64] *See* Hansen, *Where Should Humanity Aim?*, 217 (2008) ("If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, Paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm.").

[65] *See id.*; James Hansen, Storms of My Grandchildren (2009).

[66] NASA, Facts, Carbon Dioxide, http://climate.nasa.gov/vital-signs/carbon-dioxide/ (last visited May 2, 2016).

[67] United Nations, Framework Convention on Climate Change, Conference of the Parties, Paris Agreement, Article 2 ("1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by: (a) Holding the increase in the global average

emission reductions currently required by RCW 70.235.020 are not sufficient to keep the rise in surface temperature below 2°C."[68] Earth's paleoclimate history demonstrates that climate impacts accompanying global warming of 2°C or more would be irreversible and catastrophic for humanity. For example, the paleoclimate record shows that warming consistent with CO_2 concentrations as low as 450 ppm may have been enough to melt almost all of Antarctica.[69] The warming of the past few decades has brought global temperature close to if not slightly above the prior maximum of the Holocene epoch. Human society must keep global temperature at a level within or close to the Holocene range to prevent dangerous climate change. Global warming of 2°C would be well above Holocene levels and far into the dangerous range and has been described as "an unacceptably high risk of global catastrophe."[70]

The widely used models that allow for 2°C temperature increase, and therefore advocate for a global CO_2 emission reduction target aimed at a 450 ppm CO_2 standard, do not take into account significant factors that will compound climate impacts. Most importantly, they do not include the slow feedbacks that will be triggered by a temperature increase of 2°C.[71] Slow feedbacks include the melting of ice sheets and the release of potent greenhouse gases, particularly methane, from the thawing of the tundra.[72] These feedbacks might show little change in the short-term, but can hit a point of no return, even at a 2°C temperature increase, that will trigger further warming and sudden catastrophic impacts. For example, the Greenland and Antarctic ice sheets "required millennia to grow to their present sizes. If ice sheet disintegration reaches a point such that the dynamics and momentum of the process take over, reducing greenhouse gases may be futile to prevent major ice sheet mass loss, sea level rise of many meters, and worldwide loss of coastal cities—a consequence that is irreversible for practical purposes."[73]

These slow feedbacks are part of the inertia of the climate system, where "[t]he inertia causes climate to appear to respond slowly to this human-made forcing, but further long-lasting responses can be locked in."[74] Thermal inertia is primarily a result of the global ocean, which stores 90% of the energy surplus, and therefore perpetuates increased global temperature even after climate forcings, or emissions, have declined.[75] Thus, the longer we wait to reduce global CO_2 concentrations, the

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temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5° above pre-industrial, recognizing that this would significantly reduce the risks and impacts of climate change.").

[68] *Foster, et al. v. Ecology*, King County Superior Court No. 14-2-25295-1 (Department of Ecology's Response to June 23, 2015 Court Order) (filed August 7, 2015) (Exhibit K) at 4.

[69] Dec. of Dr. James E. Hansen, *Juliana et al., v. United States et al*., No. 6:15-cv-01517-TC, 14 (D. Or. Aug. 12, 2015).

[70] *Id*. at 17.

[71] Hansen, *Assessing "Dangerous Climate Change*," 15.

[72] *Id*.

[73] *Id*. at 13.

[74] *Id*. at 1.

[75] *Id*. at 4-5, 13.

more thermal inertia will already be in play and climate impacts will continue to escalate.

Furthermore, 2°C targets would lead to an increase in the use of fossil fuels that are more difficult to extract, and thus are compounded with the expenditure of greenhouse gases due to the transport and intensive mining process resulting in "more CO_2 [emissions] per unit useable energy."[76] The 2°C target also reduces the likelihood that the biosphere will be able to sequester CO_2 due to carbon cycle feedbacks and shifting climate zones.[77] Under the allowable emissions with this target, other greenhouse gases, such as methane and nitrous oxide would continue to increase, further exacerbating climate change impacts.[78] These factors are missing from the 2°C scenarios, which have been widely accepted and used in the creation of climate policies and plans.

A temperature rise of 2°C will not only lock in a further temperature increase due to thermal inertia, but it will also trigger irreversible impacts, including rapid, nonlinear sea level rise and species loss described above.[79] Most models look at sea level rise as a gradual linear response to melting ice sheets. However, "it has been argued that continued business-as-usual CO_2 emissions are likely to spur a nonlinear response with multi-meter sea level rise this century."[80] This sea level rise would occur at a pace that would not allow human communities or ecosystems to respond.

An emission reduction target aimed at 2°C would "yield a larger eventual warming because of slow feedbacks, probably at least 3°C."[81] Once a temperature increase of 2°C is reached, there will already be "additional climate change "in the pipeline" even without further change of atmospheric composition."[82] Dr. James Hansen warns that "distinctions between pathways aimed at 1°C and 2°C warming are much greater and more fundamental than the numbers 1°C and 2°C themselves might suggest. These fundamental distinctions make scenarios with 2°C or more global warming far more dangerous; so dangerous, we [James Hansen et al.] suggest, that aiming for the 2°C pathway would be foolhardy."[83] This target is at best the equivalent of "flip[ping] a coin in the hopes that future generations are not left with few choices beyond mere survival. This is not risk management, it is recklessness and we must do better."[84] Thus, a global average atmospheric concentration of CO_2 of 450 ppm, or a concentration of CO_2e between 450 and 550 ppm, would result in dangerous anthropogenic interference with the climate system and would threaten all

[76] *Id*. at 15.
[77] *Id*. at 15, 20.
[78] *Id*. at 20.
[79] *Id*. at 6.
[80] *Id*.
[81] *Id*. at 15.
[82] *Id*. at 19.
[83] *Id*. at 15.
[84] Matt Vespa, *Why 350? Climate Policy Must Aim to Stabilize Greenhouse Gases at the Level Necessary to Minimize the Risk of Catastrophic Outcomes*, 36 Ecology Law Currents 185, 186 (2009), http://www.biologicaldiversity.org/publications/papers/Why_350.pdf.

public natural resources around the world and the health and well-being of all Earth's inhabitants.

Importantly, the Intergovernmental Panel on Climate Change ("IPCC") has not established nor endorsed a target of 2°C warming above the preindustrial period as a limit below which the climate system will be stable.[85] The 2°C figure was reached as *a compromise* between the emission reduction scenarios and associated risks summarized by Working Group I of the 2007 IPCC Fourth Assessment Report,[86] and because policy makers felt that it was politically achievable.[87] As the IPCC makes clear, "each major IPCC assessment has examined the impacts of [a] multiplicity of temperature changes but has left [it to the] political processes to make decisions on which thresholds may be appropriate."[88] *Two degrees Celsius warming above pre-industrial levels has never been universally considered "safe" from either a political or scientific point of view*. As the United Nations Framework Convention on Climate Change ("UNFCCC") stated: "The 'guardrail' concept, in which up to 2°C of warming is considered safe, is inadequate and would therefore be better seen as an upper limit, a defense line that needs to be stringently defended, while less warming would be preferable."[89] And according to a Coordinating Lead Author of the IPCC's 5th Assessment Report, the 2°C "danger level" seemed:

> utterly inadequate given the already observed impacts on ecosystems, food, livelihoods, and sustainable development, and the progressively higher risks and lower adaptation potential with rising temperatures, combined with disproportionate vulnerability.[90]

The most recent IPCC synthesis of climate science confirms that additional warming of 1°C (we already have 0.9°C warming above the preindustrial average) jeopardizes unique and threatened systems, including ecosystems and cultures.[91] The IPCC also warns of risks of extreme events, such as heat waves, extreme precipitation, and coastal flooding, and "irreversible regime shifts" with additional warming.[92]

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[85] See Dec. of Dr. James E. Hansen, *Juliana et al., v. United States et al*., No. 6:15-cv-01517-TC, 5 (D. Or. Aug. 12, 2015).
[86] *See* IPCC, *Summary for Policymakers*, Climate Change 2007: The Physical Science Basis (Solomon, S., D. Qin,
M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)) (2007) (Table SPM.3).
[87] *See* Dec. of Dr. Richard H. Gammon, *Foster v. Wash. Dep't of Ecology*, No. 14-2-25295-1 SEA 1 (Wash. Super. Ct. Aug. 24, 2015).
[88] IPCC, *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report*, 125 (2014), http://report.mitigation2014.org/report/ipcc_wg3_ar5_chapter1.pdf.
[89] UNFCCC, *Report on the structured expert dialogue on the 2013–2015 review*, 18 (2015), http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf.
[90] Petra Tschakert, *1.5 °C or 2 °C: a conduit's view from the science-policy interface at COP20 in Lima, Peru*, Climate Change Responses 8 (2015), http://www.climatechangeresponses.com/content/2/1/3.
[91] IPCC, Summary for policymakers at 13-14, Climate Change 2014: Impacts, Adaptation, and Vulnerability (2014), http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf.
[92] *Id*.

4. Protect Waters of the State & Marine Life From Deadly Acidification and Warming of Ocean Waters

Conveniently, oceans have the same scientific standard of protection as the atmosphere and climate system. Marine organisms and ecosystems are already harmed and will increasingly continue to be harmed by the effects of ocean acidification. Critically important ocean ecosystems, such as coral reefs, are severely threatened by present day CO_2 concentrations of approximately 400 ppm and it is vitally important that atmospheric CO_2 levels are reduced to below 350 ppm in order to protect ocean ecosystems.[93] The IPCC never concluded that 2°C warming or 450 ppm would be safe for ocean life.[94] According to Dr. Ove Hoegh-Guldberg, one of the world's leading experts on ocean acidification and the Coordinating Lead Author of the oceans chapter of the 5th Assessment Report of the IPCC:

> Allowing a temperature rise of up to 2°C would seriously jeopardize ocean life, and the income and livelihoods of those who depend on healthy marine ecosystems. Indeed, the best science available suggests that coral dominated reefs will completely disappear if carbon dioxide concentrations exceed much more than today's concentrations. Failing to restrict further increases in atmospheric carbon dioxide will eliminate coral reefs as we know them and will deny future generations of children from enjoying these wonderful ecosystems.[95]

Even the 2015 Paris Agreement backed off of making any assumptions that 2°C is a safe level of warming though it did not state a maximum safe level of long-term warming, instead committing to pursue efforts to limit the temperature increase to 1.5°C.[96] To prevent further degradation or the eventual depletion of the oceanic resources, it is imperative that atmospheric CO_2 concentrations be returned to below 350 ppm by the end of this century.

5. The Clean Air Rule Must Be Aimed at 350 ppm and Mandate Annual Reductions of 8% Per Year

It is imperative that all states and governments around the world, including the Washington Department of Ecology, set GHG emission limits targeted at 1°C temperature change, or a maximum of 350 ppm in global CO_2 levels, in order to avoid the cascading impacts that will occur with a 2°C or 450 ppm default policy based on political feasibility rather than scientific necessity. *To reduce global atmospheric CO_2 to 350 ppm by the end of this century, this target would require that if global CO_2 emissions had flatlined with a peak in 2016, Washington emissions be reduced by 8% per year beginning in 2017, alongside Washington's share in*

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[93] *See* Dec. of Dr. Ove Hoegh-Guldberg, *Foster v. Wash. Dep't of Ecology*, No. 14-2-25295-1 SEA, 1 (Wash. Super. Ct. Aug. 24, 2015) (Exhibit M).
[94] *Id*. at 2.
[95] *Id*.
[96] Paris Agreement, Article 2, Section 1(a).

achieving 100 GtC of global CO_2 sequestration through reforestation and soil protection.[97] Continued delay makes it harder and harder for youth and future generations to protect a livable world. It is imperative to establish emission limits to put states and sovereigns around the world on a trajectory aimed for 350 ppm.

Atmospheric CO_2 levels are currently on a path to reach a climatic tipping point.[98] Absent immediate action to reduce CO_2 emissions, atmospheric CO_2 may reach levels so high that life on Earth as we know it is unsustainable at these levels. Governments have the present ability to curtail the environmental harms detailed above. Atmospheric CO_2 concentrations will decrease if states stop (or greatly reduce) their burning of fossil fuels.[99] The environmental harms and threat to human health and safety as described above can only be avoided if atmospheric CO_2 concentrations are immediately reduced. Any more delay risks irreversible and catastrophic consequences for youth and future generations.

Fossil fuel emissions must decrease rapidly if atmospheric CO_2 is to be returned to a safe level in this century.[100] Improved forestry and agricultural practices can provide a net drawdown of atmospheric CO_2, primarily via reforestation of degraded lands that are of little or no value for agricultural purposes, returning us to 350 ppm somewhat sooner.[101] However, the potential of these measures is limited. Immediate and substantial reductions in CO_2 emissions are required in order to ensure that the youth and future generations inherit a planet that is inhabitable.

6. An Additional 100 gtC Must Be Sequestered Through Reforestation & Soil Protection Measures[102]

The scientific prescription for climate recovery requires both emission reductions *and* sequestration of 100 gigatons of carbon through reforestation and soil protection.[103, 104]

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[97] Hansen Decl. (Exhibit O).
[98] James Hansen, Storms of My Grandchildren 224-30, 260 (2009).
[99] Harvey Blatt, America's Environmental Report Card xiii (2005) ("How can we stop this change in our climate? The answer is clear. Stop burning coal and oil, the sources of nearly all the carbon dioxide increase.").
[100] Hansen, *Where Should Humanity Aim?*, 217 (discussing the need to reduce the atmospheric CO_2 concentration to 350 ppm).
[101] *Id*. at 227.
[102] For an overview of the carbon cycle and sequestration potential of forests and soil, *see* Expert Declaration of Thomas Crowther, Ph.D., in support of Western Environmental Law Center and Our Children's Trust's comments on proposed Clean Air Rule, WASH. ADMIN. CODE § 173-442 (July 22, 2016) ("Crowther Decl.").
[103] Hansen et al., *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, PLOS ONE, Dec. 2013, at 1, 1, http://journals.plos.org/plosone/article/asset?id=10.1371%2Fjournal.pone.0081648.PDF.
[104] It is important to note that reforestation and sequestration efforts are not a replacement for emission reductions of at least 8% per year (2016 baseline); they are in addition to emission reductions.

> We cannot halt the rise in global surface temperatures without addressing forest and vegetation loss and degradation of soil. Furthermore, since the concentration of CO2 in the atmosphere is currently over 400 parts per million (ppm) and the safe level is no more than 350 ppm, we need to draw down this excess CO2 out of the atmosphere.[105]

Specifically, Washington must sequester at least 9,393,160 metric tons of CO_2 per year between 2012 and 2050 in order to proportionally contribute to the global prescription of 350 ppm.[106] In actuality, since Washington's forests have above average potential for carbon sequestration, Ecology should aim to sequester even more CO_2 than its average share. To comply with the scientific prescription for climate recovery, Ecology must promulgate regulations and policies that mandate sequestration *in addition* to reducing emissions.[107] Ecology's Rule fails to properly analyze sequestration in a number of ways: 1) it does not address deforestation or reforestation; 2) it does not provide for sustainable forest management practices to improve sequestration and reduce wildfires; and 3) it fails to properly consider soil carbon sequestration.

(a) Forest Carbon Sequestration is an Integral Component of Climate Recovery that Ecology Failed to Consider.

The Rule fails to properly consider possibilities for reforestation or for slowing deforestation. Washington is home to 20-21 million acres of forestland – half of its total land area.[108] State-conducted inventories report that Washington forests are net sinks of CO_2.[109] About 29 $MMtCO_2e$ are sequestered by Washington forest biomass every year.[110] Consequently, forest management is integral to any effective and enduring climate change mitigation strategy in Washington.

Washington forests are exceptional carbon sinks but deforestation poses a serious risk to their carbon storage capacity. Pacific Northwest (PNW) forests have the highest

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[105] Crowther Decl. ¶ 5.

[106] This number is calculated by multiplying the annual carbon sequestration requirement per capita for 2012-2050 by the population of Washington. Based on a global annual carbon sequestration requirement of 1.31 Metric Tons CO2 per person, EUGENE SUSTAINABILITY OFFICE, METHODOLOGY FOR ESTABLISHING A COMMUNITY CARBON BUDGET 6, *at* https://www.eugene-or.gov/DocumentCenter/View/26229, and Washington population estimates of 7,170,351 in 2015, *Washington*, UNITED STATES CENSUS BUREAU: QUICKFACTS, *at* https://www.census.gov/quickfacts/table/PST045215/53,00 (last visited July 20, 2016).

[107] Crowther Decl..

[108] GORDON BRADLEY ET AL., THE RURAL TECHNOLOGY INSTITUTE, FOREST LAND CONVERSION IN WASHINGTON STATE, *in* FUTURE OF WASHINGTON'S FOREST AND FOREST INDUSTRIES STUDY 260 (2007), http://www.ruraltech.org/projects/fwaf/final_report/index.asp.

[109] CENTER FOR CLIMATE STRATEGIES, WASHINGTON STATE GREENHOUSE GAS INVENTORY AND REFERENCE CASE PROJECTIONS, 1990-2020 I-1 (2007), http://www.ecy.wa.gov/climatechange/docs/WA_GHGInventoryReferenceCaseProjections_1990-2020.pdf; *See also* UNITED STATES GEOLOGICAL SURVEY, PROFESSIONAL PAPER 1797, BASELINE AND PROJECTED FUTURE CARBON STORAGE AND GREENHOUSE-GAS FLUXES IN ECOSYSTEMS OF THE WESTERN UNITED STATES 2 (Zhiliang Zhu and Bradley C. Reed, eds., 2012), http://pubs.usgs.gov/pp/1797/pdf/PP1797_WholeDocument.pdf.

[110] CENTER FOR CLIMATE STRATEGIES, *supra* note 7, at ES-4.

carbon stocks in the United States.[111] Forests in the western PNW are particularly effective carbon sinks due to the large presence of coniferous and old growth trees and historically infrequent fires.[112] All of these factors allow significant amounts of carbon to accumulate in PNW forests.[113] However, between 1988 and 2004, 17% of western Washington's forestland was converted to other uses.[114] Every year, an additional 0.37% to 1.04% of Washington's forestland is converted into residential or commercial development.[115] Such land use change reduces Washington's overall carbon storage capacity and thus impairs capacity for climate recovery.

Mandating carbon storage in Washington forests is vital to restoring a safe atmospheric balance of CO_2. In a report commissioned by Ecology in response to an executive order from Governor Gregoire, the 2010 Forest Carbon Workgroup expressed its belief that "conversion of forestland to non-forest uses represents one of the greatest sources of loss of forest carbon sequestration and storage, and therefore avoiding such conversion where feasible is a high priority means of reducing those losses and accompanying GHG emissions."[116] Similarly, the United Nations has stated, "combating climate change without slowing deforestation is a lost cause."[117] These conclusions are based on the scientific consensus that deforestation is "one of the largest anthropogenic sources of emissions to the atmosphere globally."[118] Net deforestation is responsible for 20% of the increase of atmospheric CO_2 globally since the preindustrial era.[119] This amounts to an additional 100 gigatons of carbon in the atmosphere.[120]

To adequately heed current science, Ecology must include regulations aimed at increasing carbon sequestration by preventing any net forest loss immediately, then promoting reforestation and more sustainable forestry practices aimed at achieving the required 9,393,159 metric tons of CO_2 sequestration per year. These measures must be *in addition* to reducing overall emissions from other sectors.

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[111] Crystal L. Raymond & Donald McKenzie, *Carbon Dynamics of Forests in Washington, USA: 21st Century Projections Based on Climate-driven Changes in Fire Regimes*, 22 ECOLOGICAL APPLICATIONS 1589, 1589 (2012).
[112] *Id.*
[113] *Id.*
[114] BRADLEY ET AL., *supra* note 6, at 269.
[115] *Id.* at 260.
[116] 2010 FOREST CARBON WORKGROUP, WASHINGTON STATE DEPARTMENT OF ECOLOGY, PUB. NO. 11-10-006, FINAL REPORT 6 (2010), https://fortress.wa.gov/ecy/publications/publications/1110006.pdf.
[117] Department of Economic and Social Affairs, *Reforestation: the easiest way to combat climate change*, UNITED NATIONS (2010), http://www.un.org/en/development/desa/news/forest/reforestation-the-easiest.html.
[118] Environmental Protection Agency, *Land Use, Land-Use Change, and Forestry*, *in* INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2014 6-54 (2016), https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Chapter-6-Land-Use-Land-Use-Change-and-Forestry.pdf.
[119] Hansen et al., *supra* note 2, at 10.
[120] *Id.*

(b) Ecology Failed to Properly Analyze Forest Health Management and Wildfire Alleviation as Methods to Improve Forest Carbon Sequestration.

Ecology has failed to properly consider forest health management or analyze the impacts of increasing intensity and frequency of forest fires on sequestration potential. Unhealthy forests increase the risk of extreme wild fires, which in turn reduce forest sequestration potential. With wildfires increasing in frequency and intensity across Washington State, managing forest health will be essential to protecting carbon storage processes.

The dangers of increased fire risk with regards to sequestration have been noted by numerous state-sponsored efforts in Washington.[121] Forest fires release carbon sequestered in forests and reduce the carbon storage capacity across the state.[122] Forest fires reduce sequestration potential by "affect[ing] the land-atmosphere exchange of [carbon] directly by releasing CO_2 to the atmosphere . . . and indirectly by shifting forest age class distributions toward a greater proportion of young forests."[123]

As climate change worsens, "Washington's forests are likely to experience significant changes in the establishment, growth, and distribution of tree species as a result of increasing temperatures, declining snowpack, and changes in soil moisture."[124] Forests also face increased threats of fire, insect outbreaks, and diseases.[125] All of these factors result in hazardous amounts of excess fuel in forests,[126] which will result in an increased frequency and intensity of wildfires in Washington.[127] In fact, Washington is already experiencing its worst fire seasons in recorded history – more than 1,000,000 acres burned in 2015 and 400,000 acres in 2014.[128] Around 13.3 million acres – greater than half – of Washington forests are at moderate to high risk for fire.[129]

Despite the huge importance of forest carbon sequestration in climate recovery, Ecology's Rule fails to consider or recommend any methods for restoring and maintaining the health of Washington's forests to avoid the detrimental impacts of severe wildfires on Washington's sequestration potential. While Ecology does not directly

[121] 2010 FOREST CARBON WORKGROUP, *supra* note 14, at 11.
[122] *Id.*
[123] Raymond & McKenzie, *supra* note 9, at 1589-90.
[124] WASHINGTON STATE DEPARTMENT OF ECOLOGY, PUB. NO. 14-01-006, WASHINGTON GREENHOUSE GAS EMISSION REDUCTION LIMITS 12 (2014), https://fortress.wa.gov/ecy/publications/documents/1401006.pdf.
[125] *Id.*
[126] 2010 FOREST CARBON WORKGROUP, *supra* note 14, at 11.
[127] CENTER FOR CLIMATE STRATEGIES, *supra* note 7, at I-5.
[128] WASHINGTON FOREST PROTECTION ASSOCIATION, ANNUAL REPORT 2015 (2015), http://www.wfpa.org/workspace/resource/document/wfpa-2015-annual-report.pdf.
[129] DUSHKU ET AL., WINROCK INTERNATIONAL, CARBON SEQUESTRATION THROUGH CHANGES IN LAND USE IN WASHINGTON: COSTS AND OPPORTUNITIES 4 (2005), http://www.ecy.wa.gov/climatechange/twgdocs/agr/051707agrwestcarb2.pdf.

manage state and private forest lands,[130] Ecology is the agency established "to manage and develop our air and water resources in an orderly, efficient, and effective manner."[131]

(c) Ecology Failed to Mandate Soil Protection and Enhancement as a Means to increase Washington's Carbon Sequestration Potential.

Finally, the proposed Rule fails to require measures to increase and protect soil carbon sequestration. Through both organic matter and inorganic compounds, "soil is a large reservoir of carbon."[132] Soil organic matter stores about three times more carbon than forests and other vegetation.[133] Every 1% increase in average soil organic carbon content has the potential to reduce CO_2 in the atmosphere by up to 2%.[134] Methods for improving soil carbon sequestration include the application of compost,[135] diversifying planting practices on farms, and adding biochar to soils.[136]

In addition, agricultural soils in Washington store an estimated 1.4 $MMtCO_2e$ per year[137] but have the potential to store much more with management aimed at improving sequestration.[138] The agricultural sector could improve soil carbon storage capacity through sustainable farming practices such as efficient fertilizer use and solid manure management.[139] Ecology must produce soil protection guidelines and encourage and incorporate such methods into the Rule to comply with the scientific prescription. Ecology is in the process of developing a general discharge permit for Concentrated Animal Feeding Operations on the state.[140] As part of this permit, Ecology is able to mandate manure management practices that are designed to enhance the state's sequestration potential. In its current form, the draft permit does nothing to do that, but measures can and should be incorporated into the final version of the permit. By failing to mandate soil carbon sequestration and sustainable agriculture practices, Ecology ignores processes pivotal to climate recovery in Washington.

Ecology has failed to properly consider the sequestration potential of forests and soil in the proposed Rule. To comply with the current scientific consensus that effective

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[130] The Washington Department of Natural Resources manages state trust lands, including forests, on behalf of the people of Washington.
[131] RCW 43.21A.020.
[132] WASHINGTON STATE DEPARTMENT OF ECOLOGY, FOCUS ON SOIL CARBON SEQUESTRATION 1 (2013), https://fortress.wa.gov/ecy/publications/publications/1307031.pdf.
[133] *Id.*
[134] *Id.*
[135] W*hat is Carbon Farming?*, MARIN CARBON PROJECT, http://www.marincarbonproject.org/what-is-carbon-farming (last visited July 15, 2016).
[136] WASHINGTON STATE DEPARTMENT OF ECOLOGY, at 2-3; Crowther Decl. at 5.
[137] CENTER FOR CLIMATE STRATEGIES, at ES-4.
[138] WASHINGTON STATE DEPARTMENT OF ECOLOGY, PUB. NO. 15-07-005, SOIL ORGANIC CARBON STORAGE (SEQUESTRATION) PRINCIPLES AND MANAGEMENT vii (2015), https://fortress.wa.gov/ecy/publications/publications/1507005.pdf.
[139] *Sources of Greenhouse Gas Emissions,* UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, https://www3.epa.gov/climatechange/ghgemissions/sources/agriculture.html (last visited July 18, 2016).
[140] Ecology, Concentrated Animal Feeding Operation General Permit, *at* http://www.ecy.wa.gov/programs/wq/permits/cafo/index.html (last visited July 22, 2016).

climate recovery initiatives must include sequestration improvements, Ecology must address factors such as reforestation, forest management, soil carbon sequestration, and sustainable agricultural practices in its Rule.[141] These sequestration initiatives must be *in addition* direct reductions in Washington's GHG emissions.[142] Forest and soil management are not an alternative to reducing emissions but rather a discrete, pivotal component of any effective climate recovery plan.

b. The Proposed Clean Air Rule is Not Targeted To Achieve 350 ppm By the End of the Century

i. Ecology's Proposed Rule is Designed to Reduce Washington Emissions by Roughly 1% Per Year, Which Is Illegal

Ecology must fully analyze and disclose annual emission reduction rates relative to statewide emissions in order to understand the full impact of the rule on all of the emissions for which Washington must control and reduce. Because that analysis does not exist, our calculations show that for the first 3 years the rate of reduction relative to statewide emissions is only ~0.92% per year, gradually increasing through 2036, but still at rates far beneath the 8% required if emission reductions began in 2017 based on a 2016 flatline peak. However because Ecology's rule delays actual emission reductions until 2018, and far later for many sectors, Ecology's proposed emission reductions are even further off track from the best science, which by 2018 would require at least 8.5 percent annual reductions, coupled with carbon sequestration in soils and forests.[143]

ii. The Proposed Rule Regulates An Insufficient Number of Sources

In the proposed Clean Air Rule, Ecology fails to regulate a sufficient number of greenhouse gas emissions sources. The proposed rule claims to cover only 66% of overall state greenhouse gas emissions.[144] By establishing an excessively high compliance threshold (starting at 100,000 MT of CO_2e dropping to 70,000 MT of CO_2e) and failing to regulate some of the state's most significant emission sectors, the agency proposes a severely inadequate emissions reduction scheme. In *Foster v. Ecology*, the court found that Ecology's current climate change policies did not "preserve, protect and enhance the air quality for current and future generations."[145] Under the current proposed rule, Ecology continues to narrow the scope of the rule, to exclude some of the largest state emissions sources, including transportation, industrial forestry, agriculture, and corporations that emit less than 70,000 MT of CO2e. *Ecology has the authority, and legal obligation, to create a comprehensive and more stringent rule and set standards for all*

[141] *See* Crowther Decl., *supra* note 1, at 3.
[142] Hansen et al., *supra* note 2, at 1.
[143] *See* Hansen Decl. (Exhibit O), ¶¶ 70, 82, 84.
[144] *See* Department of Ecology, *SEPA Environmental Checklist - Clean Air Rule at 5*, available at http://www.ecy.wa.gov/programs/air/rules/docs/173442sepacheck-2.pdf. As discussed above, Ecology's claim that it actually regulates 66% of emissions is dubious.
[145] *Foster v. Wash. Dep't of Ecology*, No. 14-2- 25295-1 SEA, 6 (Wash. Super. Ct. Nov. 19, 2015) (Exhibit D).

emissions sources.[146] In order to ensure the protection of current and future generations, Ecology must expand the rule to cover all major sources of GHG emissions in the state of Washington.

1. Ecology Must Regulate Transportation Emissions

In the proposed Clean Air Rule, Ecology does very little to require actual reductions of state transportation emissions. Washington's transportation sector accounts for the largest percentage of greenhouse gas emissions, approximately 44%, and thus must be regulated in the proposed Clean Air Rule.[147] The state has recognized that "addressing [transportation] emissions is key to achieving Washington's statutory greenhouse gas reduction goals (RCW 70.235.020)."[148] The *Foster* court noted that Ecology has not adequately addressed transportation emissions in existing policies and thus suggested that Ecology is obligated to address transportation emissions in the Clean Air Rule in order to protect the rights of young people.[149]

The proposed rule provides an option for covered parties to obtain ERUs through existing commute trip reduction programs. However, this provision is of little value. Commute trip reduction program emission reductions are separate from the proposed rule, and are presumed to occur even without the rule. As a result, any ERUs generated under commute programs are non-additional to overall emissions reductions. It is illogical for emission reductions from the commute trip reduction generated ERUs to be counted in determining transportation sector emission reductions.

Ecology's delayed regulation of petroleum fuel producers and importers does not suffice to address the state's tremendous amount of GHG emissions from transportation. Ecology has essentially ignored the back end of the problem, i.e. the emissions from combustion of fossil fuels by vehicles. Within the transportation sector, "the consumption of gasoline in vehicles is the largest single source of emissions in Washington . . . accounting for over 23% of total emissions in 2010."[150] The bottom line is that Ecology does not explicitly set emissions standards for or regulate transportation sector emissions in the rule, leaving to our children the challenge of emission reductions in this significant sector. There is no question that Ecology has the existing legal authority to regulate emissions resulting from the sale of petrochemical products (gasoline, diesel, propane, etc.), or vehicle emissions specifically, as illustrated by its

[146] RCW § 70.94.331.

[147] "In Washington, the transportation sector is the largest source of emissions, accounting for over 44% of total emissions in 2011." *See* Department of Ecology, *Washington Greenhouse Gas Emission Reduction Limits: Report prepared under RCW 70.235.040,* at 8 available at https://fortress.wa.gov/ecy/publications/documents/1401006.pdf.

[148] Life Cycle Associates, LLC for WA Office of Financial Management, A Clean Fuel Standard in Washington State, Revised Analysis With Updated Assumptions DRAFT (September 29, 2014), *at* http://www.ofm.wa.gov/initiatives/cleanfuelstandards/Documents/Carbon_Fuel_Standard_evaluation_2014_draft.pdf (last visited July 22, 2016) at 8.

[149] *Foster v. Wash. Dep't of Ecology*, No. 14-2- 25295-1 SEA, 6-7 (Wash. Super. Ct. Nov. 19, 2015) (Exhibit D).

[150] Leidos, Evaluation of Approaches to Reduce Greenhouse Gas Emissions in Washington State – Final Report (October 14, 2013) at 7.

development of a draft Clean Fuel Standard. The Legislature has not taken that authority away and it must be implemented as part of the Clean Air Rule. For example, all distributors of gasoline, diesel, or propane could be required to reduce the emissions resulting from the sale of those products by 8 percent per year.

4. Ecology Must Regulate Emissions from New and Retrofitted Buildings

Residential, commercial, and industrial greenhouse gas emissions represent 22-30% of Washington's GHG emissions.[151] To address these emissions, Ecology must establish emissions standards for new or retrofitted buildings to ensure that new buildings are not locking in old energy-inefficient infrastructure and that the emissions for which they are responsible meet the limits set by Ecology, consistent with science-based standards. The new emission standards for buildings must put Washington on track to achieve a rate of reductions for this sector, which when combined with other sectors, will equal the total annual emission reductions required by the best science. We are not asking Ecology to change existing state law regarding energy-related building standards,[152] but rather that Ecology acknowledge the reality that buildings are sources of GHG emissions and should be regulated as such.

3. Ecology Must Regulate Industrial Forestry

Ecology must do more to limit industrial logging emissions by regulating the industrial forestry sector under the Clean Air Rule. At present, Ecology fails to properly disclose or analyze GHG emissions from the forestry sector, even though those emissions trigger reporting requirements under existing state law.[153] A recent study critiques the global accounting practice used in assessing forest sector GHG emissions, which lumps timber industry emissions with carbon sequestered on forest conservation land.[154] Ecology cannot fall into the same trap and assume that all GHG emissions from the forestry sector are counteracted by forest sequestration. Instead, Ecology must include GHG emissions from the forestry sector in its GHG inventory and regulate the forestry sector as part of its emission reduction regime.

4. Ecology Must Regulate Emissions from Agriculture

Ecology's proposed rule also fails to regulate agricultural activities (including manure management and fertilizer use), which are responsible for a sizeable amount of GHG emissions in the state.[155] The failure to regulate agriculture makes no sense,

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[151] *See* Department of Ecology, Climate Change, Frequently asked questions about the Washington Clean Air Rule (July 21, 2016), at http://www.ecy.wa.gov/climatechange/CarbonRuleFAQ.html; RCW § 19.27A.130.
[152] RCW 19.27A.
[153] RCW 70.94.151(5)(a).
[154] JOHN TALBERTH ET AL., CENTER FOR SUSTAINABLE ECONOMY, CLEARCUTTING OUT CARBON ACCOUNTS 1 (2015), http://sustainable-economy.org/wp-content/uploads/2015/11/Clearcutting-our-Carbon-Accounts-Final-11-16.pdf.
[155] *Sources of Greenhouse Gas Emissions,* UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, https://www3.epa.gov/climatechange/ghgemissions/sources/agriculture.html (last visited July 18, 2016).

especially in light of the fact that the agricultural sector seeks to benefit substantially from Ecology's proposal to count agricultural activities as recognized as generating emission reduction units.[156] In 2012, agricultural soils in Washington emitted 1.7 MMTCO2e and manure management was responsible for another 1.2 MMTCO2e.[157] Together with emissions from livestock through enteric fermentation, the agricultural sector was responsible for around 5.4% of Washington's total emissions in 2012.[158]

Concentrated Animal Feeding Operations (CAFOs) are major contributors of greenhouse gas emissions ("GHG") in the state of Washington. "Agricultural activities such as manure management, fertilizer use, and livestock (enteric fermentation) result in methane and nitrous oxide emissions that account for 6% of State GHG emissions in 2005."[159] Worldwide, the livestock sector generates more GHG emissions as measured in CO_2 equivalent (18%) than the transportation sector.[160] Livestock generates 65% of human-related nitrous oxide which has 296 times the global warming potential of CO_2, accounts for 37% of all human-induced methane[161] and is responsible for 64% of ammonia emissions: devastating health effects. *Id.* Global greenhouse gas emissions from the agricultural sector totaled 4.69 billion tons of carbon dioxide (CO_2) equivalent in 2010 (the most recent year for which data are available), an increase of 13 percent over 1990 emissions. By comparison, global CO_2 emissions from transport totaled 6.76 billion tons that year, and emissions from electricity and heat production reached 12.48 billion tons, according to Worldwatch Institute's Vital Signs Online service (www.worldwatch.org)."[162] Manure management activities have been identified as a major contributing factor to increased GHG emissions:

> Manure that is deposited and left on pastures contributes to global nitrous oxide emissions because of its high nitrogen content. When more nitrogen is added to soil than is needed, soil bacteria convert the extra nitrogen into nitrous oxide and emit it into the atmosphere—a process called nitrification. Emissions from manure on pasture were highest in Asia, Africa, and South America, accounting for a combined 81 percent of global emissions from this source.[163]

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[156] WAC 173-442-160(6).
[157] WASHINGTON STATE DEPARTMENT OF ECOLOGY, 2010 WASHINGTON STATE GREENHOUSE GAS EMISSIONS INVENTORY (2012), http://www.ecy.wa.gov/climatechange/docs/2012GHGtable.pdf.
[158] *Id.*
[159] WA Department of Community, Trade & Economic Development, Washington State Greenhouse Gas Inventory and Reference Case Projections, 1990-2010 (December 2007), *available at* http://www.ecy.wa.gov/climatechange/docs/WA_GHGInventoryReferenceCaseProjections_1990-2020.pdf (last visited March 31, 2014).
[160] Livestock's Long Shadow – Environmental Issues and Options, United Nations Food & Agriculture Organization (Nov. 29, 2006).
[161] This assumes that methane causes 23 times as warming as CO_2, but as discussed below, this measure of warming is outdated. Methane is now estimated to cause 34 times the amount of warming of CO_2.
[162] Worldwatch Institute, "Agriculture and Livestock Remain Major Sources of Greenhouse Gas Emissions," available at http://www.worldwatch.org/agriculture-and-livestock-remain-major-sources-greenhouse-gas-emissions-1 (last visited March 31, 2014).
[163] *Id.*

In Washington, "[t]he manure management category [of emissions], which shows the highest rate of growth relative to the other categories, accounted for 11% [] of total agricultural emissions in 1990 and is estimated to account for about 25% [] of total agricultural emissions in 2020."[164] The science is clear that livestock population is a critical component of any emissions calculation for the agricultural sector. *Id.* The GHG emissions calculations done in Washington for the agricultural sector explicitly recognize the need for more precise data because "[e]missions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors which are derived from several variables including manure production levels, volatile solids content, and CH_4 formation potential)." *Id*. at F-6.

In 2012, the leading source of methane in the United States was enteric fermentation, and manure management was the fifth largest source.[165] Activities associated with manure management are also the third largest source of nitrous oxide, another powerful greenhouse gas.[166] In Washington State, enteric fermentation was responsible for 2.0 million metric tons of CO_2 equivalents ("MMT CO2eq") and manure management was responsible for 1.1 MMT CO_2eq in the year 2010.[167]

Methane is produced by ruminants during the digestion process. Furthermore, anaerobic conditions in manure holding areas and runoff lagoons lead to methane emissions. The EPA website estimates that one cow produces up to 110 kg of methane per year.[168] Nitrous oxide, a powerful greenhouse gas,[169] is also produced from combined manure and urine during storage. In addition, the farm equipment, generators and boilers used at the feedlot facility and heavy-duty diesel trucks transporting livestock and feed will produce carbon dioxide from fuel usage and from electricity usage. Diesel-powered engines and generators are also a significant source of black carbon. If Ecology wants to give the agricultural industry the economic benefit of generating emission reduction units, it must also treat agriculture as a covered party under the rule.

5. Ecology Must Regulate Consumption-based Emissions

Ecology must do a greenhouse gas emissions inventory that includes consumption-based emissions. A consumption-based emissions inventory is a greenhouse gas inventory including estimates of embedded emissions associated with the

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[164] WA Department of Community, Trade & Economic Development, Washington State Greenhouse Gas Inventory and Reference Case Projections, 1990-2010 (December 2007), *available at* http://www.ecy.wa.gov/climatechange/docs/WA_GHGInventoryReferenceCaseProjections_1990-2020.pdf (last visited March 31, 2014) at F-4.

[165] USEPA, Inventory of US Greenhouse Gases and Sinks: 1990-2012 2-4 (Apr. 15, 2014).

[166] *Id*. at 2-5.

[167] WA Dept. of Ecology, WASHINGTON STATE GREENHOUSE GAS EMISSIONS INVENTORY 1990-2010 at 4 (2012).

[168] See http://www.epa.gov/rlep/faq.html, last visited May 21, 2014.

[169] Myhre et al, IPCC AR5 Chapter 8 at 714 (N_2O GWP = 298 over 100 years and 268 over 20 years).

life cycle of materials and services, including electricity and fuels, consumed in Washington. These emissions are included regardless of whether they physically originate in Washington. A consumption-based inventory uniquely counts out-of-state emissions associated with producing the products, services, and fuels consumed in Washington. It also counts emissions associated with producing fuels that are used to generate electricity consumed in Washington. Ecology has not provided a consumption-based inventory for CO_2 emissions, which would include all embedded CO_2 emissions for goods produced outside of Washington and consumed within Washington. Without this inventory and analysis, Ecology cannot accurately account for all of the State's emissions sources to ensure that it is fulfilling its constitutional and statutory mandate to protect the rights of young people and future generations.

Oregon is a model state for accounting for consumption emissions. The state has recognized that Oregon households' consumption affects the global environment and contributes to climate change.[170] In order to assess more complete carbon footprint, the State developed a scheme to include out-of-state production emissions for products consumed within the state. Emissions are counted if they satisfy households' economic final demand.[171] The inventory includes emissions associated with tangible commodities such as food, vehicles, appliances, furnishings and electronics. It also includes services, fuels, and electricity.[172] The inventory helps Oregon "design strategies that lower the carbon intensity of goods and services consumed by Oregonians and create incentives for Oregon's in- and out-of-state suppliers to shift to production methods that reduce their carbon footprint.[173] Ecology has failed to include emissions standards for consumption emission reductions into the rule. In order to effectively address all of Washington's GHG emissions, Ecology must 1) prepare a consumption-based inventory of Washington GHG gases and 2) set consumption emission reduction emission standards as part of the Clean Air Rule.

6. <u>Ecology Must Lower the Threshold for Covered Parties</u>

Ecology must lower the threshold for parties to be covered under the rule in order to adequately reduce atmospheric CO_2 levels. The current threshold schedule is arbitrary and not based on sound science. Under the proposed rule, the first compliance period includes covered parties with annual emissions greater or equal to 100,000 MT CO_2.[174] The compliance threshold gradually decreases by 5,000 MT CO_2 each compliance period until it reaches 70,000 MT CO_2 in 2035, after which the threshold remains at 70,000 MT CO_2. So in essence, Ecology is legalizing the emission of massive amounts of CO_2 and makes it impossible for the state to reduce its GHG emissions in the manner prescribed

[170] *See* Oregon Department of Environmental Quality, Oregon Department of Energy, Oregon Department of Transportation, *Oregon's Greenhouse Gas Emissions Through 2010: In-Boundary, Consumption-Based and Expanded Transportation Sector Inventories* (July 18, 2013) at 9, available at http://www.oregon.gov/deq/AQ/Documents/OregonGHGinventory07_17_13FINAL.pdf.
[171] *Id.*
[172] *Id* at 29.
[173] *Id* at 9.
[174] Clean Air Rule, Wash. Admin. Code § 173.442.110(3) (proposed May 31, 2016); WAC § 173.442.030(3).

by best available climate science. The thresholds selected by Ecology grossly deviate from current state and federal reporting requirements as well as other cap and trade programs. In Washington, facilities and transportation fuels suppliers emitting at least 10,000 MT CO_2 of greenhouse gases are statutorily required to report their emissions.[175] It follows, then, that Ecology has express legislative approval to regulate sources that exceed more than the 10,000 MT CO_2 threshold.

Additionally, the EPA reporting threshold is 25,000 MT CO_2.[176] California's reporting threshold is 25,000 MT CO_2, and the state also requires entities whose annual emissions equal or exceed 25,000 MT CO_2 of GHG emissions to comply with the state cap-and-trade program.[177] To date, Ecology has offered no justification for deviating from either the 10,000 MT CO_2 or 25,000 MT CO_2 thresholds or failing to connect its established thresholds to science-based levels of emission reductions. In order to be on track to adequately reduce statewide emissions, Ecology should lower the compliance threshold to at least match the GHG emission reporting threshold of 10,000 MT CO_2.

Washington's Clean Air Act provides Ecology broad authority to cover significantly more parties that what is proposed in the current draft of the rule.[178] Pursuant to the Washington Clean Air Act, Ecology is charged with securing and maintaining the ". . .levels of air quality that protect human health and safety. . ."[179] In order to reduce atmospheric CO_2 emissions to 350 ppm by the end of the century, it is imperative that Ecology regulate a significantly larger segment of GHG emitters.[180]

iii. <u>The Proposed Rule Illegally Delays Compliance & Contradicts Ecology's Own Findings that Urgent Action is Needed to Draw Down GHG Emissions</u>

After detailing the devastating impacts all sectors of Washington will face in light of climate change, in December 2014 Ecology proclaimed:

> If we delay action by even a few years, the rate of reduction needed to achieve these goals would have to be beyond anything achieved historically and could be very costly.
>
> * * *
>
> Climate change is not a far off risk. Globally, it is happening now and is worse than previously predicted, and it is forecasted to get worse.

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[175] RCW § 70.94.151 (5)(a) ("The department shall adopt rules requiring persons to report emissions of greenhouse gases as defined in RCW 70.235.010 where those emissions from a single facility, source, or site, or from fossil fuels sold in Washington by a single supplier meet or exceed ten thousand metric tons of carbon dioxide equivalent annually.").
[176] 40 C.F.R. § 98.2.
[177] Cal. Code Regs. tit. 17, §§ 95812, 95101.
[178] RCW § 70.94.331.
[179] RCW § 70.94.011.
[180] *See* Hansen, et al. *Assessing 'Dangerous Climate Change.'*

> We are imposing risks on future generations (causing intergenerational inequities) and liability for the harm that will be caused by climate change that we are unable or unwilling to avoid.[181]

In spite of this finding, which simply reiterates what the agency has been saying for years,[182] Ecology has arbitrarily allowed a twenty-year "phase-in" for covered parties to come into compliance with the requirements of the rule. It is unfathomable for Ecology to sanction such a long delay for implementation of the rule in light of its own findings regarding the urgency of the climate crisis. The Clean Air Rule must require immediate reductions of GHG emissions if we are to have any hope of contributing to the resolution of the climate crisis. We have a very small window of opportunity to achieve global concentrations of 350 ppm by the end of the century and Ecology's "kick the can down the road" approach is unlawful.

iv. The Emissions Threshold Arbitrarily Does Not Continue To Decrease After 2035

Remarkably, Ecology does not decrease the emissions threshold after 2035, a time when the young people of today will be experiencing more severe impacts of living in a climate-changed world. Ecology offers no justification for this. Given the science that clearly demonstrates the need and feasibility of a achieving net-zero carbon economy in Washington state,[183] it is illegal for Ecology to sanction such dangerous levels of GHG emissions after 2035.

v. The Proposed Rule Arbitrarily Relies Upon A Flawed Washington GHG Reporting Program

The current GHG reporting program (GHGRP) rules does not cover all petroleum products, and appears to be limited to "liquid motor vehicle fuel, special fuel, or aircraft fuel." This should be clarified and addressed by Ecology. Are liquefied petroleum gases and all other petrochemical products covered by the reporting program? If so, they should be regulated under the proposed Clean Air Rule.

Even under its current GHGRP, Ecology is 4 years behind in reporting emissions data. Our consultant has provided up to date emissions data for WA through 2015 based on the EPA Tool and EIA SEDS data.[184] This level of information on emissions and the trajectory are a major failing of the proposed rule.

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[181] Ecology, Washington Greenhouse Gas Emission Reduction Limits, Ecology Publication No. 14-01-006 (December 2014) at 18.

[182] *See, e.g.,* Ecology, Path to a Low Carbon Economy, Ecology Publication No. 10-01-011 (December 2010) at 1 ("Global climate change is the economic and environmental issue of our lifetime. The science is clear that we must move forward quickly to reduce greenhouse gas (GHG) emissions in order to mitigate its effects. Without action, climate change will negatively affect nearly every part of Washington's economy through changes in temperature, sea level, and water availability.").

[183] *See* Jacobson Decl. (Exhibit P).

[184] See Exhibit Q (Washington Emissions Data Compared to Science-Based Emissions Reductions-OCT).

Further, Ecology intends to update the reporting methodology and requirements for GHG reporting in preparation for the Clean Air Rule implementation in a way that, when the updates take effect, expected emissions from individual fuel providers will change (based upon the new methodology) and entities that currently appear that they would be covered or not covered under the program based on old data may switch to being covered or not covered when the new reporting methodology comes into effect. However, none of this is clear in the proposed rule, which leaves a tremendous amount of uncertainty for the public and industry. Furthermore, an accurate reporting system is a necessary first step towards fulfilling Ecology's obligation to address climate change.

vi. The Rule's Reliance on Offsets is Flawed

(a) The proposed Rule Allows Ecology to Delegate Responsibility for the Creation of Offsets and their Attendant Emissions Reductions to Other State Agencies and External Carbon Registries.

Ecology's strong reliance on the use of offsets is ill advised.[185] The proposed rule establishes a compliance obligation WAC 173-442-200(3) that must be met with emissions reductions by the end of each compliance period as measured in Emissions Reduction Units, which are equivalent to one metric ton of CO2e WAC 173-442-020(1)(m). According to Ecology's cost-benefit analysis, covered parties may, individually or in combination:

A. Reduce emissions on-site at the covered party, or obtain the equivalent of similar reductions from other covered or voluntarily participating parties.
B. Offset emissions using an in-state emissions reduction project or program, including RECs, as allowed by the proposed rule.
C. Purchase emissions allowances through existing carbon markets if allowed by the proposed rule.[186]

In their analysis, Ecology forecast a range of compliance costs per MT CO2e for each compliance option. The estimated costs are:

Emission reduction programs (Renewable Energy Credits): $3 – $11 per MT CO2e
Emissions reduction projects: $5 – $29 per MT CO2e
Market emissions reductions: $13 – $14 per MT CO2e
On-site emissions reductions: $23 – $57 per MT CO2e[187]

The cost-benefit analysis acknowledged that:

[185] For a more thorough description of the problems associated with offsets, *see* the comments submitted by Food and Water Watch on the proposed Clean Air Rule.
[186] Preliminary Cost-Benefit and Least Burdensome Alternative Analysis, p. 13.
[187] *Id.* p. 14-15.

> Actual costs depend on the method of compliance chosen, and Ecology assumes that covered parties will choose the lowest-cost option available to them. In order, these are RECs, in-state emissions reduction projects, market purchases, and on-site emissions reductions.[188]

These projected results highlight the importance of offset projects and programs under the proposed rule, given that Ecology expects them to be preferred by covered parties given their more favorable economics. Further, as a centerpiece to the proposed rule, Ecology identifies a wide range of projects and programs that can generate offset credits, and indeed encourages polluters to take advantage of offsets rather than reducing their own emissions in the state. This is the wrong approach.

As the agency responsible for operating and enforcing any Washington GHG reduction program, Ecology is legally obligated to ensure that its verification criteria are met. However, the proposed rule shifts responsibility for determining projects and programs that generate offset credits to other state agencies and external registry programs, and provides contradictory provisions as to eligible programs, making Ecology's job of policing offsets criteria virtually impossible.

A key criterion for offset credit is that the emissions reductions must be "[a]dditional to existing law or rule" and cannot be used if "[i]f an emission reduction is required by another statute, rule, or other legal requirement." WAC 173-442-150 Nevertheless, the proposed rule would allow emissions reductions from the following already-existing "policies" to create ERUs and be used for compliance: (1) The EPA Clean Power Plan; (2) The Washington GHG emissions performance standard; (3) The Washington CO2 mitigation standard for fossil-fueled thermal electric generation facilities; and (4) Commute trip reduction programs.

To the extent that emission reductions are required by these programs, their use for the creation of offsets would lead to double-counting and violate the additionality criterion. To generate ERUs, sectors include transportation, combined heat and power, energy, livestock and agriculture, waste and wastewater, and industrial sectors. The proposed rule establishes exceedingly complicated and poorly specified processes to determine actual emissions reductions and the generation of ERUs from activities and programs within these sectors. WAC 173-442-160. They include protocols from established registries or state agency processes to establish the eligibility of activities and programs in each sector, and the ensuing emissions reductions that Ecology would rely on to assign ERUs. The sole responsibility for Ecology for offsets would be to "assign the appropriate quantity of ERUs." WAC 173-442-160.

For each sector, other entities besides Ecology would be responsible for determining emissions reduction activities and programs and the resulting emission reductions. However, for each of these sectors, emissions reductions may also be determined through a methodology approved by Ecology, with Ecology assigning a value

[188] *Id*. p. 23.

for a quantity of ERUs. WAC 173-442-060. Ecology's ability to judge whether or not projects and programs meet established criteria, especially the critical criterion of non-additionality, would be highly compromised given that these offsets would be administered by separate agencies and held to the standards of different registry protocols.

Finally, nowhere in the proposed rule is it specified how covered parties can acquire offset credits or the ERUs deemed created by Ecology, by funding projects and programs, purchasing credits from the responsible parties, or other means. The failure of the proposed rule to spell out how the marketplace for offset credits would operate is an enormous and inexplicable gap in the design of the proposed offset program.

(b) The Excessive Role Envisioned for Allowances Would Impose Costs and Deny Benefits to Washingtonians.

The proposed rule establishes purchases of allowances from external multisector GHG emission reduction programs as a compliance option. WAC 173-422-110(3). The proposed rule sets limits on how much of a covered party's compliance obligation can be met through allowances, starting at 100% for the first two compliance periods and declining slowly over time. WAC 173-442-170. Ecology's focus should be on requiring polluters to install the technology needed to minimize the pollution. Ecology should not be legalizing the continued discharge of dangerous levels of GHG emissions. Such an approach puts those in close proximity to the polluting facilities in harms way. Those are precisely the people Ecology is supposed to be protecting.

As an initial matter, the proposed rule states that allowances must be "derived from methodologies congruent with chapter 173-441 WAC."[189] This chapter is Washington's GHG reporting rule. Allowances are not the same as activities that generate GHG emissions reductions reportable to the Washington system. Rather, they are officially-sanctioned authorizations by air quality regulators allowing a certain amount of GHG emissions to be emitted. It is unclear what this provision seeks to accomplish.

The ability of covered parties to use allowances for all or most of their compliance obligations prioritizes perceived market efficiencies over equally important non-market factors. Ecology's cost-benefit analysis acknowledges that there are trade-offs between in-state reductions and allowances. For example, the cost-benefit analysis identifies important pollution and environmental justice factors to weigh against the use of allowances. It acknowledges that reductions in associated emissions such as criteria pollutants and toxic air pollutants can have major public health benefits.[190] Ecology identified a number of population groups living near GHG emissions facilities: children, the elderly, minorities, and low-income, linguistically-isolated, and less educated populations. While each of these groups living near covered facilities stand to benefit from on-site emissions reductions, Ecology declined to analyze the tradeoffs between

[189] Id. p. 18.
[190] Id. p. 39

these. This is reflected in the proposed rule, which leaves it up to covered parties to decide which compliance options to use based on their monetary costs alone. Ecology's assumption that on-site emission reductions will be selected last by covered parties makes it highly likely that Washingtonians are not going to see the potential benefits of a rule that regulates actual GHG emissions.

(c) Ecology Must Create Opportunities for Public Involvement in the Implementation of Any GHG reduction Program.

Any offset program should be fully transparent and involve public participation in implementation, such as third-party verification of reductions, the assignment of emissions to entities that do not have reported emissions, and the assignment of ERUs to offset projects. We believe that a vehicle for public oversight should be established under the rule to provide the public with opportunities to participate directly in the state's efforts to reduce GHG emissions. In California, oversight committees were established during the initial operations of the CA Cap and Trade Program, including an Emissions Market Assessment Committee and an Economic and Allocation Advisory Committee. A public oversight committee should include representatives of groups interested in the achievement of GHG reductions in Washington and communities disproportionately impacted by GHG pollution and climate change.

V. ECOLOGY'S COST BENEFIT ANALYSIS IS FLAWED

a. The Social Cost of Carbon Estimates Require Reductions Based on Science

i. Ecology is Required to Consider the Real Costs & Benefits of the Proposed Clean Air Rule.

Under RCW 34.05.328, the Department of Ecology is required to "[d]etermine that the probable benefits of the rule are greater than its probable costs, taking into account both the qualitative and quantitative benefits and costs and the specific directives of the statute being implemented." Ecology assessed some costs in its Preliminary Cost-Benefit and Least Burdensome Alternative Analysis.[191] In this analysis, Ecology estimates the value of reducing GHG emissions based on the social cost of carbon (SCC) developed by the federal government and the expected trajectory of GHG reductions as covered parties meet their GHG emission reduction pathways. The SCC developed and used by the federal government estimates economic damages expected from increases in carbon dioxide emissions, monetized as dollars per metric ton.[192] The damages from climate change assessed in the SCC include "changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning."[193] The

[191] Ecology Publication No. 16-02-008 (June 2016).
[192] EPA, "The Social Cost of Carbon," (Last updated Feb. 23, 2016) available at https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html (last visited July 7, 2016).
[193] *Id.*

purpose of the SCC, pursuant to Executive Order 12866, is to enable governmental agencies to include the social benefits of reducing CO_2 emissions when conducting cost-benefit analyses on regulatory actions that affect global emissions.[194] We applaud and support Ecology's use of the SCC as part of its rulemaking process, especially since the most significant social costs of climate change will be experienced by the young and future generations. It is important that those costs are weighed against the minimal costs imposed on the corporations who are to be primarily regulated under the rule. We also support Ecology's focus on global damage estimates as opposed to solely domestic estimates because of the inherent global nature of climate change. That being said, we offer the following comments to improve the accuracy of Ecology's analysis.

ii. The U.S. Social Cost of Carbon Analysis Undervalues the Rights of Children & Future Generations.

For 2015, the U.S. has estimated the SCC range as between \$11 and \$105 per metric ton; for 2020, the range is between \$12 and \$123.[195] When these estimates are viewed as "avoided costs," they represent the dollar value of the benefits from avoiding future damages caused by climate change. However, the U.S. (and now Ecology) erroneously uses unreasonably high discount rates as a key component of the SCC, which discounts future benefits more steeply than near-term benefits, thereby valuing adults of the present generation more highly than children and all future generations, in violation of long-standing principles of evolutionary biology[196] and morality, as well as legal rights of youth and future generations. Discount rates essentially are used to calculate the present value of future damages,[197] and are represented as percentages. The federal government uses four discount rates to calculate a range of present values for the average annual SCC forecast by three integrated assessment models. The discount rates are 5%, 3%, 2.5%, and the 95th percentile at 3%, the high end of the distribution of potential future damages.[198] Higher discount rates give less value to future damages and yield lower present values and, alternatively, lower discount rates give greater value to future damages and yield higher present values.[199] The federal government uses a range of

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[194] U.S. Interagency Working Group on Social Cost of Carbon, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," at 3 (May 2013) available at http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf (last visited July 7, 2016).

[195] U.S. Interagency Working Group on Social Cost of Carbon, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," at 3, 13 (May 2013, Revised July 2015) available at https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf (last visited July 8, 2016).

[196] Trivers, R.L. 1972. Parental Investment and Sexual Selection. In B. Campbell, ed. Sexual Selection and the Descent of Man, 1871-1971, Aldine-Atherton, Chicago, pp. 136-179, *at* http://roberttrivers.com/Publications_files/Trivers%201972.pdf (last visited July 20, 2016) (defining parental investment as "any investment by the parent in an individual offspring that increases the offspring's chance of surviving (and hence reproductive success) at the cost of the parent's ability to invest in other offspring.").

[197] EPA, EPA Fact Sheet, "The Social Cost of Carbon," at 1 (Dec. 2015) available at https://www3.epa.gov/climatechange/Downloads/EPAactivities/social-cost-carbon.pdf (last visited July 11, 2016).

[198] *Id.*

[199] *Id.* at 2

discount rates "because the literature shows that the [SCC] is highly sensitive to the discount rate and because no consensus exists on the appropriate rate to use for analyses spanning multiple generations."[200] The 2.5% discount rate is not, as Ecology suggests, the most appropriate discount rate and the SCC values derived from a 2.5% discount rate should not be valued as the most likely SCC.[201] Rather, the range of costs produced by the SCC are simply meant to cover a range of future damage estimates. The 2.5% discount rate applied by Ecology is too high and, therefore, inappropriate for use in its cost-benefit analysis.

iii. <u>Ecology's Estimates Improperly "Discount" Children & Future Generations</u>

Agencies using the SCC developed by the U.S. Interagency Working Group rely on estimates that do not adequately represent the costs of climate change to children and future generations.

According to the 2010 Technical Support Document of the Interagency Group:

> With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ [discount rate] in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than ρ = 0 would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).[202]

Nevertheless, although estimates for appropriate discount rates of future generations ranged from 1% to 3%,[203] the Working Group chose 3% as the central value. The Working Group "consistently chose relatively high discount rates available, without explaining its rejection of alternative lower ones."[204] Of the four major uncertainties that exist in applying economics to future climate change impacts, the Interagency Working Group selected "the option[s] that minimize[] estimates of climate risks and damages."[205]

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[200] *Id.*
[201] AIR QUALITY PROGRAM, WASHINGTON STATE DEPARTMENT OF ECOLOGY, PRELIMINARY COST-BENEFIT AND LEAST-BURDENSOME ALTERNATIVE ANALYSIS, CHAPTER 173-442 WAC, 1, 12, 60 (2016) *at* https://fortress.wa.gov/ecy/publications/SummaryPages/1602008.html (last visited July 19, 2016).
[202] U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866" at 21 (February 2010) available at https://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf
[203] *Id.* at 21
[204] Laurie T. Johnson and Chris Hope, *J Environ Stud Sci*, "The social cost of carbon in U.S. regulatory impact analyses: an introduction and critique," at 8 (Sept. 2012) available at http://www.ourenergypolicy.org/wp-content/uploads/2012/09/fulltext.pdf (last visited July 11, 2016).
[205] Frank Ackerman and Elizabeth A. Stanton, "Climate Risks and Carbon Prices: Revising the Social Cost of Carbon," at 6 (2011) available at http://sei-us.org/Publications_PDF/SEI-Climate-Risks-Carbon-Prices-2011-full.pdf (last visited July 11, 2016).

By selecting these lower-risk options, the Working Group ignores "increasingly ominous scientific evidence about climate risks [that] impl[y] much greater losses at higher temperatures."[206] These risks must be considered when determining the SCC because "[b]y the time we know what climate sensitivity and higher temperature damages turn out to be, it will be much too late to do anything about it."[207]

The EPA acknowledges that current SCC modeling does not account for all important damages.[208] There is a noted absence in the models of many physical, ecological, and economic impacts predicted by current climate science.[209] In responding to comments on the development of the SCC, the Interagency Working Group acknowledged that two of the three models used to derive an average SCC do not account for variability in the climate that could affect agriculture.[210] Additionally, the models used in the SCC do not accurately, or at all, account for feedback loops such as ocean circulation patterns, forest diebacks, sea ice melt, and permafrost melt.[211] Experts with the Natural Resources Defense Council found the models "likely to understate impacts by excluding a large number of factors that would increase it while excluding only a very small number of countervailing forces."[212] Moreover, the models used to develop the SCC omit climate change damages to fisheries, forests, and resource scarcity due to migration.[213] A 2014 study found that the SCC should be no lower than $125 per metric ton based on an aggregate of studies using high and low discount rates, and even this value, which is marginally larger than federal estimates, was considered "realistic and conservative."[214] Further, some studies find *negative* discount rates may be more appropriate for estimating the SCC.[215]

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[206] *Id.* at 13
[207] *Id.* at 19
[208] EPA, "The Social Cost of Carbon," (Last updated Feb. 23, 2016) available at https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html (last visited July 7, 2016).
[209] *Id.*
[210] Interagency Working Group on Social Cost of Carbon, United States Government, "Response to Comments: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, at 15 (July 2015) available at https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-response-to-comments-final-july-2015.pdf (last visited July 11, 2016).
[211] *Id.*
[212] Johnson and Hope at 3 (Sept. 2012) available at http://www.ourenergypolicy.org/wp-content/uploads/2012/09/fulltext.pdf (last visited July 11, 2016).
[213] Environmental Defense Fund, Institute for Policy Integrity, Natural Resources Defense Council, "Social Cost of Carbon Pollution Fact Sheet," (April 2014) available at http://costofcarbon.org/files/Cost_of_Carbon_Fact_Sheet.pdf (last visited July 19, 2016); *See also* U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," 1, 11 (Feb. 2010) available at https://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf (last visited July 19, 2016).
[214] Jacobson et al., *Energy Environ. Sci.*, "100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States," Supplement at 26 (2015) available at https://web.stanford.edu/group/efmh/jacobson/Articles/I/USStatesWWS.pdf (last visited July 11, 2016).
[215] *See, e.g.*, Fleurbaey, Marc and Zuber, Stephane, "Climate policies deserve a negative discount rate," Chicago Journal of International Law: Vol. 13: No. 2, Article 14, 565, 592 (2013) available at http://chicagounbound.uchicago.edu/cgi/viewcontent.cgi?article=1381&context=cjil (last visited July 15, 2016).

Ecology estimates the present value of avoided GHG emissions under the proposed rule over a 20-year period as $14.5 billion, which is a vast underestimate.[216] Governor Inslee stated in Executive Order 14-04 that "the effects of climate change on water supplies, public health, coastal and storm damage, wildfires, and other impacts, will cost Washington almost $10 billion per year after 2020" based on a study by the University of Oregon.[217] Governor Inslee also stated that "studies conducted for the Western Climate Initiative indicated that a program to limit carbon emissions, implemented through market mechanisms, would result in a net increase of 19,300 jobs and increased economic output of $3.3 billion in Washington by 2020."[218]

Another indicator that Ecology's estimate of the benefits of the rule is underestimated is its failure to take into account the Social Cost of Methane (SCM).[219] Estimates of the SCM range from roughly $490 to $1500/MT in 2015 (in 2012 dollars) at discount rates of 5% and 2.5% respectively.[220] The SCM has been adopted by EPA in recent regulatory impact analyses.[221] In its cost-benefit analysis, Ecology failed to account for methane's much greater impact on climate and its much higher social cost. According to the Washington GHG Inventory, methane emissions were estimated from the natural gas and wood products sectors at .9 $MMTCO_{2e}$, roughly 1% of total GHG emissions. As noted above, methane is highly likely to be emitted by other sectors and we expect actual methane emissions to be significantly higher than those reported in the Inventory. If roughly half of the methane emissions reported in the Inventory were eliminated by the CAR, it would add roughly $32 million to the benefits under the rule.

Furthermore, Governor Gregoire, in Executive Order 12-07 stated:

> Washington is the country's top provider of farmed oysters, clams, and mussels. Our shellfish growers employ directly and indirectly more than 3,200 people around the state and provide an annual total economic contribution of $270 million statewide. The increasing levels of acidification in Washington's marine waters pose serious and immediate threats to our shellfish resources, and the revenue and jobs supported by the shellfish industry.[222]

The UW Climate Impact Group reports that "[b]y the end of the century, ocean

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[216] AIR QUALITY PROGRAM, WASHINGTON STATE DEPARTMENT OF ECOLOGY, PRELIMINARY COST-BENEFIT AND LEAST-BURDENSOME ALTERNATIVE ANALYSIS, CHAPTER 173-442 WAC, at 39.
[217] Exec. Order No. 14-04: Washington Carbon Pollution Reduction and Clean Energy Action, 1 (2014) available at http://www.governor.wa.gov/sites/default/files/exe_order/eo_14-04.pdf (last visited July 19, 2016).
[218] *Id.* at 2
[219] Marten *et al*., Incremental CH_4 and N_20 mitigation benefits consistent with the U.S. Government's SC-CO_2 estimates, Climate Policy,15:2, 272-298 (2015).
[220] Regulatory Impact Analysis of the Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector, US Environmental Protection Agency, 2015 *at 4-14*. Available at https://www3.epa.gov/airquality/oilandgas/pdfs/og_prop_ria_081815.pdf
[221] *Id.*
[222] Executive Order No. 12-07 (Nov. 27, 2012), *at* http://www.ecy.wa.gov/water/marine/oa/MRAC_ExecutiveOrder_12-07.pdf (last visited July 20, 2016).

acidification is projected to result in a 40% reduction, globally, in the rate at which mollusks (e.g., mussels and oysters) for shells, as well as a 17% decline in growth, and a 34% decline in survival."[223] These numbers serve as examples that the estimated $14.5 billion in avoided costs is much lower than the actual avoided costs of climate change. Many other Washington-specific costs (e.g loss of forest land due to wildfires, loss of tidelands due to sea level rise, etc.), are incorrectly omitted from this equation.

Finally, the "pure discounting" approach taken by the federal government values harm and death to future generations as only a fraction of the value of harm and death to the present generation.[224] Discounting has been criticized as violating intergenerational neutrality, favoring the present generation over future generations.[225] Applying higher discount rates in determining the SCC diminishes future generations' rights to life, liberty, due process, and equal protection. Thus, a social cost of carbon analysis that applies a discount rate to the lives of future generations is manifestly unconstitutional and will lead to unconstitutional policies that lock in dangerous levels of warming, such as the proposed Clean Air Rule in its current form.

iv. Ecology's Estimates Are Inadequate

Ecology estimates the SCC for present and future generations of Washingtonians based on the SCC developed by the federal government, but many assumptions and parameters used in Ecology's estimates equate to grossly inadequate values. First, Ecology is basing the SCC on a 20-year timeframe. This timeframe is not only shorter than that utilized by the federal government, but the most severe climatic damage will occur beyond the 20-year mark. Second, Ecology fails to account for many important damages that climate change will bring, including physical, ecological, and economic impacts on both the local and global scale. Last, as stated above, evidence suggests that the discount rate used by the federal government favors the present generation over future generations and that the actual SCC is much higher than current SCC estimates. While we support Ecology's use of the SCC in its economic analysis, it requires revision for the reasons set forth above.

VI. THE RULE ARBITRARILY EMULATES CAP & TRADE PROGRAMS IN OTHER JURISDICTIONS THAT ARE NOT WORKING & FAILS TO DIRECTLY REGULATE EMITTERS AND SAFEGUARD AGAINST LEAKAGE AND MARKET INSTABILITY

The ERU system, the centerpiece of Ecology's Proposed Clean Air Rule, is modeled on cap-and-trade programs, such as California's, that do not adequately reduce emissions and, if pursued, must be accompanied by strong, direct regulation of emission

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223 UW Climate Impacts Group, State of the Knowledge Report – Climate Change Impacts & Adaptation in Washington State: Technical Summaries for Decision Makers (2013), *at* https://cig.uw.edu/resources/special-reports/wa-sok/ (last visited July 20, 2016) at 8-4.
224 John E. Davidson, Amicus Curiae Brief, *Juliana v. United States*, at 29 (Feb. 24, 2016)
225 David A. Weisbach & Cass R. Sunstein, "Climate Change and Discounting the Future: A Guide for the Perplexed," 27 Yale Law and Policy Review 433, 435 (2009).

sources. The Proposed Rule relies upon a market based system that will fail to result in anything near the reductions needed; an approach that actually risks market instability. To remedy this, Ecology must ensure that rule requires actual, on-site emission reductions, coupled with a cap-and-trade approach that incorporates safeguards not currently in place in this Proposed Rule's ERU program.

(a). Cap-and-trade programs alone do not result in the emissions reductions necessary to address the risks of climate change

Ecology's exclusive reliance on a cap-and-trade model as the primary component of its emissions reduction program ignores the fact that other jurisdictions, such as California, have not achieved clear emissions reductions from these types of programs. For example, while California's cap-and-trade program has been portrayed as the centerpiece of efforts to halt climate change, it only accounts for a small proportion of targeted emission reductions. [226] In fact, to this point, it has not resulted in any measurable reductions in emissions.[227] This is consistent with the results of other market-based programs, which tend to be aimed more at assuaging business concerns rather than actually reducing GHG emissions. We understand that corporations feel they need to continue to profit at the expense of young people and future generations, but Ecology's Proposed Rule is a giant corporate giveaway that does not make the covered parties pay into the ERU trading system created by the rule.

(b) Existing Cap-and-Trade Programs Suffer from Leakage

Ecology's Proposed Rule, in allowing offsets and failing to include safeguards, risks leakage and the negation of any real emissions reductions, as well as market instability. To protect against these issue, Ecology must include safeguards in the rule, such as tighter restrictions on offsets. Leakage occurs when the actual total amount of emissions are not reduced, but are rather shifted so as to make it appear that an entity has reduced emissions.[228] Broadly allowing offsets risks, as the Proposed Rule does, risks widespread leakage and a failure to produce any reduction in emissions. To protect against this catastrophe, Ecology should review the language in AB32 in California which aimed to ensure leakage was minimal.[229] Ecology must, however, avoid California's, subsequent mistake, where negotiations with industry resulted in a series of exemptions that now allow for carbon leakage that potentially matches the quantity of carbon in the market.[230] Not only does this negate any positive impact of California's

[226] *See, e.g.*, California Carbon Dashboard. *Cap and Trade.* http://calcarbondash.org/. Last accessed 007/21/16. Noting California Cap-and-Trade aims to result in 22% of the programs total emission reductions).
[227] *See, e.g.*, Food and Water Watch Comment Letter (July 22, 2016) at ¶ 11.
[228] David Roberts. *California's Carbon Market is Leaking*. Grist. (Oct. 30, 2014).
[229] *Id. See* California Health and Safety Code (2014: §§ 35852(b), (b)(8)).
[230] *Id. See, also*, Danny Cullenward. *How California's Carbon Market Actually Works*. 70 Bulletin of the Atomic Scientists 35, 39 (2015).

cap-and-trade program, it may be, in part, responsible for the reduction in demand for carbon credits in May's auction.[231]

Recently, California's carbon credit auction resulted in only 10% of credits available being purchased. Analysts suggest that the causes of this dismal auction outcome involved three primary issues, two of which are issues specific to California's tax structure and statutory guidelines.[232] The third, however, overproduction of credits, results from leakage and emissions shuffling. Ecology's Proposed Rule must be modified to ensure that its ERU program does not suffer from the same sort of leakage that California's rule does. To do so, it must further limit reliance on offsets and ensure that the ERUs are allocated for true emission reductions and not as a result of shuffling or other activities that mask an industry's continued emissions.[233].

Ecology's proposed rule emulates aspects of the California cap-and-trade approach, without the additional regulations needed to reduce emissions and without sufficient safeguards, such as tight controls on offsets, to reduce leakage. It therefore fails to adequately cap emissions while risking instability greater than that that has occurred in California. In promulgating this rule, Ecology not only ensures that Washington's attempt to combat climate change is minimal and unlawful, but that this state will not lead in the effort to reduce emissions as envisioned by the Legislature and Governor Inslee. In addition, the destabilization and failure of the ERU program will result in and reinforce anxiety in other states about the risks of diverse approaches to emissions reduction. By creating a rule that directly acts to reduce emissions at the source and, for any cap-and-trade component of that rule, taking into considerations the lessons offered by California and other jurisdictions, Ecology has the opportunity to remedy this before this Proposed Rule becomes cemented as active regulation.

VII. ECOLOGY HAS THE LEGAL TOOLS IT NEEDS TO REDUCE WASHINGTON'S SHARE OF EMISSIONS ON A PATH TARGETED TO 350 PPM BY THE END OF THE CENTURY

In addition to Ecology's Constitutional obligation to protect public trust resources, Ecology has ample legal authority to require more stringent emission reductions targeted to achieving 350 ppm by the end of the century. Ecology has been entrusted with protecting Washingtonians' health and safety[234] through the management

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[231] *See*, Danny Cullenward and Andy Coghlan. *Structural Oversupply and Credibility in California's Carbon Market*. 29, The Electricity Journal 7, 14 (2016).
[232] Commentators believe the current legal challenge, based on Proposition 13's requirement that new taxes be supported by a two-third vote of the legislature, will not be successful. While the original statutory authority to initiate the cap-and-trade program possibly ends 2020, the legislature recently released a series of amendment's that would continue the program through 2030. *See* Dan Walters, *Could California's 'cap-and-trade' auction meltdown happen again?* The Sacramento Bee. (June 13, 2016). http://www.sacbee.com/news/politics-government/politics-columns-blogs/dan-walters/article83098292.html Last accessed July 19, 2016.
[233] *See*, *e.g.*, Wara Comment Letter on Proposed Clean Air Rule ¶¶ 5, 6.
[234] Wash. Rev. Code § 43.21A.010 (1970); Wash. Rev. Code § 70.94.011 (1991); Wash. Rev. Code § 34.05.328 notes (1995).

of air and water resources.[235] Moreover, it must do its part to stabilize global climate levels.[236] In order to achieve these goals, and comply with its other statutory obligations described above, Ecology has rulemaking authority to adopt rules and regulations that protect Washingtonians' "fundamental and inalienable right . . . to live in a healthful and pleasant environment."[237] In addition, Ecology has a specific mandate to promulgate rules "establishing air quality objectives and air quality standards."[238] The department must fulfill its duties by managing and developing air and water resources,[239] providing sound science to facilitate development of state electric power resources,[240] limiting GHG emissions by complying with state law and regularly providing scientifically-informed recommendations to the Legislature,[241] and mitigate harmful pollution and ocean acidification impacts to Washington's waters.[242] Additionally, Ecology has been entrusted with the protection of air quality for current and future generations and securing air quality levels to protect Washingtonians' health and safety.[243] The department must adopt rules and emission standards[244] "as expeditiously as possible"[245] to ensure air quality contaminant levels do not reach levels that endanger human health and the environment.[246] Ecology must leverage their current authority to implement policies to ensure Washington is on track to achieve an annual 8% GHG emissions reduction.

(a) 100% Renewable Energy System By 2050

A 100% renewable U.S. energy system can be achieved within the next thirty-five years without acquiring carbon credits from other countries. In other words, actual physical emissions of CO_2 from fossil fuels can be eliminated with technologies that are now available or reasonably foreseeable. This can be done at a reasonable cost by eliminating fossil fuel subsidies and creating annual and long-term CO_2 reduction targets. Net U.S. oil imports can be eliminated in about 25 years, possibly less. The result will also include large ancillary health benefits from the significant reduction of most regional and local air pollution, such as high ozone and particulate levels in cities, which is mainly due to fossil fuel combustion.[247] Experts have:

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[235] RCW § 43.21A.020.
[236] RCW § 70.235.020 (1)(a)(iii).
[237] RCW § 43.21A.010.
[238] RCW 70.94.011(2)(a).
[239] RCW § 43.21A.020.
[240] RCW § 43.21A.600 (2009).
[241] RCW § 70.235.020; RCW § 70.235.040.
[242] Wash. Rev. Code § 43.27A.90(8) (1988); Wash. Rev. Code § 90.48.30 (1987); Wash. Rev. Code § 90.48.80 (1987).
[243] RCW § 70.94.011.
[244] Wash. Rev. Code § 70.94.331(2)(a)-(c) (1991).
[245] RCW § 70.94.011.
[246] *Id.*
[247] *See* Mark Z. Jacobson et al., *100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for the 50 United States,* 8 Energy & Envtl. Sci. 2093 (2015) (for plans on how the United States and over 100 other countries can transition to a 100% renewable energy economy see www.thesolutionsproject.org); Arjun Makhijani, Carbon-Free, Nuclear-Free: A Roadmap for U.S. Energy Policy (2007); *see generally* Mark Z. Jacobson declaration, attached hereto as Exhibit P.

> found transitioning by 2050 to be economically feasible for every state. Importantly, states on schedule to transition to 100% renewable energy by 2050 will also reduce their emissions on the “350 by 2100”-trajectory, the pace needed to return atmospheric CO_2 levels to 350 parts/million by the year 2100, in line with the prescription stated by Dr. James Hansen and other expert climatologists.[248]

Experts state that approaches to transition to a renewable energy system and to phase out fossil fuels by about 2050 include: A cap on fossil fuel use that declines to zero by 2050 or a gradually rising carbon tax with revenues used to promote a zero-CO_2 emissions energy system and to mitigate adverse income-distribution effects; increasingly stringent efficiency standards; elimination of direct and indirect subsidies and other incentives for fossil fuel extraction, transportation, and combustion; investment in a vigorous and diverse research, development and demonstration program; banning new coal-fired power plants and phasing out existing coal-fired power plants; adoption of a policy that would aim to have essentially carbon-free state and local governments, including almost all of their buildings and vehicles by 2030; and adoption of a gradually increasing renewable portfolio standard for electricity until it reaches 100% by about 2050.[249] Products and services already exist for building or remodeling buildings to have zero GHG emissions; for generating sufficient electricity with zero carbon dioxide emissions; for zero-emission transportation and industrial processes; and agricultural and forest processes that can also decrease GHG emissions and increase CO_2 sequestration. Governments around the world, including Washington, must fully consider and implement these measures in achieving their own annual emissions reduction measures to transition off of fossil fuels.

Furthermore, experts have already prepared plans for U.S. states, including Washington, as well as for over 100 countries that demonstrate the technological and economic feasibility of transitioning off of fossil fuels toward 100% of energy, for all energy sectors, from clean and renewable energy sources: wind, water, and sunlight by 2050. It is time to put these plans into action.

(b) Transitioning to 100% Clean and Renewable Energy by 2050 in Washington Is Possible & Necessary

Ecology can lead and facilitate Washington’s transition to 100% clean and renewable energy by 2050. Expert-prepared plans are already available to ensure Washington can meet emission reductions required by the best climate science. All that is missing is a comprehensive regulatory program by Ecology to facilitate and compel the transition. Reforming the energy system (in all sectors, including transportation) is technically and economically feasible, and in fact will be beneficial to Washingtonians and the state economy. Mark Jacobson, of Stanford University, is an expert who has

[248] Jacobson Decl. at ¶ 5.
[249] *See id*.

prepared a detailed plan for Washington and has offered a declaration in support of these comments on behalf of youth and future generations.[250] The plan outlines the means by which solar, hydro and geothermal energy can take over the service now provided by fossil and bio-fuels across Washington State. *See* Figure 1. Additionally, the plan outlines policy measures needed to ensure Washington can transition to 100% renewable energy by 2050.

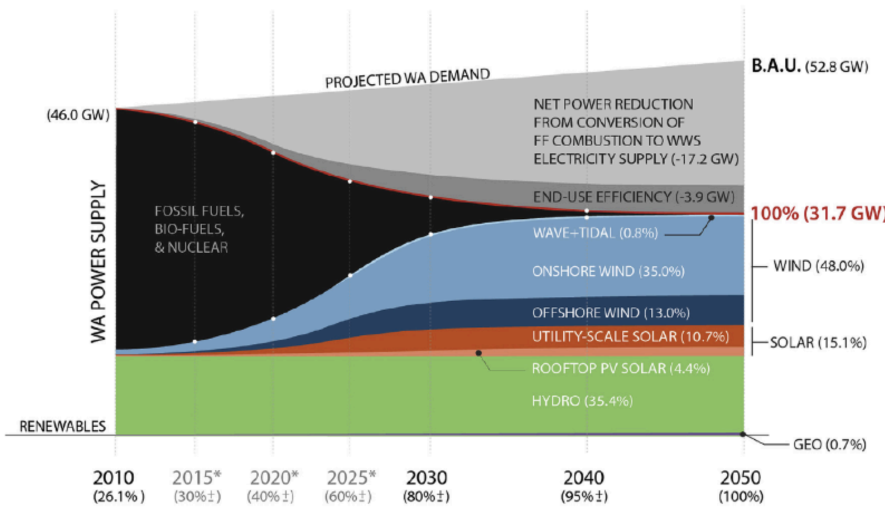

Fig. 4. Change in Washington State end-use all-purpose (electricity, transportation, heating/cooling, and industry) supply and demand over time with business as usual (BAU) versus WWS. Total power demand decreases upon conversion to WWS due to the efficiency of electricity over combustion and end-use energy efficiency measures. The 100% demarcation in 2050 indicates that 100% of all-purpose power is provided by WWS technologies by 2050, and the power demand by that time has decreased. The numbers in parentheses are values in 2050. The percent conversions assumed in the figure are 30% by 2015, 40% by 2020, 80% by 2030, 95% by 2040, and 100% by 2050. Karl Burkart (personal communication).

(i) <u>Other Policy Options for Ecology</u>

A wide array of emissions reduction policy options are available for Ecology to implement using its existing legal authority. We recognize the challenges the state has faced in light of our legislature's recalcitrance to address climate change. But fortunately previous legislators, who took their job seriously as trustees of the state's natural resources, gave us the tools we need to resolve this crisis. By implementing a combination of policies, instead of solely relying on the flawed Clean Air Rule, Ecology can more effectively and efficiently reduce Washington's emissions. Furthermore, it is in both Ecology's and the public interest for Ecology to collaborate with as many Executive agencies as possible and serve as a leader on the issue of climate change. An interdepartmental approach to climate change will result in the most robust and lasting change.

Much work has been done in regards to the policy measures that should be implemented to allow the state to reduce its GHG emissions.[251] What is missing from Ecology, however, is the implementation and enforcement of the recommended policies.

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[250] Mark Z. Robinson Declaration, attached as Exhibit P.

[251] *See, e.g.,* Ecology, Path to a Low-Carbon Economy: An Interim Plan to Address Washington's Greenhouse Gas Emissions, Ecology Publication No. 10-01-011 (December 2010); Leidos, Evaluation of Approaches to Reduce Greenhouse Gas Emissions in Washington State – Final Report (October 14, 2013).

Ecology has the legal tools it needs to both require science-based emission reductions and to achieve them by setting emissions standards and implementing a wide array of complementary policies that when implemented will put Washington on a path to do its part to address global climate change and ocean acidification. Given the breadth of Ecology's authority under the Clean Air Act, it can regulate all sources of pollution in the state by establishing air emission standards and limitations for those sources, including the electricity sector, building sector, transportation sector, industrial sector, agricultural sector, consumption sector, etc. Ecology will need to work in tandem with and collaboratively with other agencies and authorities as well in order to shift the systemic reliance on a fossil fuel-based energy system in all sectors, towards a renewable-based energy system. But to be clear, only Ecology is specifically charged with regulating emissions and setting standards and limits for those emissions. It cannot evade that statutory mandate simply because other agencies have overlapping authority that also affect emission levels. Ecology must lead, as mandated by the legislature. Climate change cannot be somebody else's problem.

As examples, Ecology has the authority to implement all of the following policies and should thoroughly consider, evaluate and disclose the emission reduction potential of each of these policy mechanisms in its analysis of the proposed Clean Air Rule. Ultimately, it is up to Ecology to determine the appropriate policy make-up to achieve science-based emission reductions on track with the 350 ppm prescription. However, Ecology has not demonstrated that its current policy proposal, the Clean Air Rule, will be able to achieve emission reductions and thus these alternatives need to be considered. Thus, the following panoply should be considered:

1. Clean Energy Fund

Ecology should develop a Clean Energy Fund to offset costs of transitioning to renewable and clean energy and to administer a comprehensive regulatory scheme to reduce state emissions according to the best science and Ecology's legal mandate. Clean Energy Funds are typically comprised of fees from consumer electricity bills or from electric utilities.[252] Here however, the Fund could include fees charged to industries that emit GHGs, such as the petroleum refinery, production, or fuel distribution sector. These funds can be used in research and development of clean energy technologies and training, infrastructure upgrades, as well as sponsoring energy efficiency programs. For example, Clean Energy Fund fees may be collected by charging electricity consumers or by collecting or charging contributions from electric utility companies or other companies responsible for GHG emissions.[253]

Any regulatory fee should be directly linked to the social costs associated with emissions, achieving appropriate science-based levels of emissions reductions, and

[252] *See* Public Benefit Funds, Center for Climate and Energy Solutions, http://www.c2es.org/us-states-regions/policy-maps/public-benefit-funds (last visited July 5, 2016); U.S. Dept. of Energy, http://energy.gov/savings/public-benefits-funds-renewables-and-efficiency (last visited July 21, 2016); Open Energy Information, http://en.openei.org/wiki/Public_Benefits_Fund (last visited July 21, 2016).
[253] *Id.*

funding the regulatory program. Based on a report from Oregon, a fee on carbon of $150 a ton would only get Oregon about halfway to its (scientifically-inadequate) goal of reducing GHG emissions to 75% below 1990 levels.[254] Even a regulatory fee on carbon of $150 per metric ton is well below the estimated cost to remove one metric ton of carbon from the atmosphere, which is around $600 per ton.[255] Therefore, a regulatory fee on carbon is not likely to be sufficient on its own to meet Washington's required GHG emission reductions, but coupled with other efforts, is an important policy option for Ecology to consider.[256]

The Washington Clean Air Act, administered by Ecology, directs state and local agencies to "lessen the negative environmental impact of . . . project[s] on all environmental media, including air, water, and land" when choosing air pollution control strategies.[257] Furthermore, the Act directs that "the costs of protecting the air resource and operating state and local air pollution control programs shall be shared as equitably as possible among all sources whose emissions cause air pollution."[258] In accordance with the Act's policy to "safeguard the public interest," the Washington Clean Air Act, administered by Ecology, "provide[s] for the use of all known, available, and reasonable methods to reduce, prevent, and control air pollution."[259] The Department is "authorized to adopt such rules and regulations as are necessary and appropriate to carry out the provisions of this Chapter," RCWA 43.21A.80, and as to the development of electric power resources, the Director "may represent the state and aid and assist the public utilities therein to the end that its resources shall be properly developed in the public interest insofar as they affect electric power . . . ."[260] Ecology has full authority to impose regulatory fees in administering a comprehensive program to reduce GHG emissions without infringing on the taxation power of the legislature.[261] Accordingly, Ecology should do the following:

- Impose regulatory fees on electric utilities and other industries directly emitting or responsible for emissions from the sale of their products

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[254] Oregon Legislative Revenue Office, *Economic and Emissions Impacts of a Clean Air Tax of Fee in Oregon (SB306)* 5 (Dec. 2014), available at http://www.pdx.edu/nerc/sites/www.pdx.edu.nerc/files/carbontax2014.pdf.
[255] Earth Challenge, *The Implications of Demonstrating the Economic Removal of Carbon Dioxide* (Nov. 4, 2015), http://www.pdx.edu/nerc/sites/www.pdx.edu.nerc/files/carbontax2014.pdf.
[256] The passage of a carbon tax (e.g. Initiative 732) can also be used to facilitate the transition to clean energy and reduce the amount needed to be charged by a regulatory fee. Because that requires the passage of new law, we have not included a carbon tax on the list of policy options Ecology can and should implement.
[257] RCW § 70.94.011.
[258] *Id.*
[259] RCWA 70.94.011.
[260] RCWA 43.21A.605.
[261] In Washington, a regulatory fee is distinguished from a tax if the following conditions are met 1) the primary purpose of the fee " is to pay for a regulatory scheme, a particular benefit conferred, or mitigation of the burden created;" 2) "the money allocated [is] only to an authorized purpose;" and 3) "there is a direct relationship between the fee charged and the service received by those who pay the fee or between the fee charged and the burden produced by the fee." *Storedahl Properties, LLC v. Clark County*, 178 P.3d 377, 382-5 (Wash.App. Div. 2, 2008). The Clean Energy Fund and its fees would clearly meet the test and qualify as a regulatory fee.

greater than 10,000 mtC, where the funds go into a Clean Energy Fund and are used for energy efficiency and clean energy projects.

- Provide permits to emit that include costs for GHG emissions, which feed into the Clean Energy Fund.
- Develop funding projects that allow utilities, property owners, businesses, and individuals access to Clean Energy Fund funds to assist their emission reduction efforts, with special consideration to low-income and disadvantaged communities.

2. New Building Emission Reductions and Green Building

Residential, commercial, and industrial greenhouse gas emissions represent 22% of Washington's GHG emissions.[262] As discussed earlier, Ecology must establish emissions standards for new or retrofitted buildings to ensure an expansion of energy efficiency measures. Additionally, technology already exists to implement Zero Energy Building (ZEB) standards. A ZEB is defined as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."[263] Thus, Ecology should consider the following in its proposed rule:

- Establish building emissions standards for new construction or retrofits to ensure expansion of energy efficiency measures that result in 100% carbon neutral buildings.
- Require all non-permitted businesses, including landlords, to do a carbon footprint audit that results in energy efficiency recommendations and make the Clean Energy Fund available for qualified projects.
- Provide support to the State Building Code Council, as needed, to ensure building codes are consistent with new emission standards and the legislature's goal that by at least the year 2031, new homes and buildings will have zero fossil-fuel emissions.[264] The legislature has found that energy efficiency is the "cheapest, quickest, and cleanest way to meet rising energy needs, confront climate change, and boost our economy."[265]

3. Electricity Sector Emission Reductions

The electricity sector represents 20% of Washington's GHG emissions. Direct electricity production emissions can be addressed through the transition from fossil fuels to renewable energy. Washington's electricity sector must eliminate coal, petroleum, and natural gas and transition to a 100% wind, water, and solar energy plan. In order to do

[262] *See* Department of Ecology, Climate Change, Frequently asked questions about the Washington Clean Air Rule (July 21, 2016), at http://www.ecy.wa.gov/climatechange/CarbonRuleFAQ.html.
[263] *See* United States Department of Energy, *A Common Definition for Zero Energy Buildings* (September 2015) at 4, available at http://energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf.
[264] RCW § 19.27A.020.
[265] RCW § 19.27A.130.

this, utilities must enhance the current infrastructure to more efficiently generate, store, and distribute renewable energy electricity. These efforts can be facilitated by a Clean Energy Fund, which can provide funds for projects to increase generation capacity and storage and to ensure the most efficient electricity transmission. Ecology has the authority to establish a fund, to set emissions standards, and to provide guidance to utilities in transitioning to a 100% renewable energy system.

Renewable Portfolio Standard

Washington currently has a Renewable Portfolio Standard that "requires large utilities to obtain fifteen percent of their electricity from new renewable resources."[266] The current statutory renewable energy targets are nine percent by 2016 and fifteen percent by 2020.[267] Ecology does not need to wait for the Legislature to enact new statutory targets. Rather, the department must utilize its existing authority to expand the standard to require utilities incorporate 80% renewable energy by 2030 and 100% renewables by 2050, which are technically and economically feasible.[268] Accordingly, Ecology must do the following:

- Expand Washington's Renewable Portfolio Standard to require large utilities to obtain 80% of their electricity from new renewable resources by 2030 and 100% by 2050.

Renewable Energy Funding Projects

In order to efficiently transition to a 100% renewable energy sector, systems must be in place to create a robust energy infrastructure. The Clean Energy Fund provides a way for Ecology to offset the costs associated with transitioning to renewable energy. Ecology should develop multiple avenues for utilities, property owners, businesses, and individuals (especially from low-income areas and with special consideration of communities of color who are facing environmental injustice issues) to access funds to support renewable energy projects. Energy project funds may support energy efficiency improvements, sequestration activities, transitioning to 100% renewable energy sources, the elimination of diesel and gas backup generators, and other projects that reduce GHG emissions. Ecology should consider establishing the following funding projects:

- Develop a Property Assessed Clean Energy Program (PACE) that uses Clean Energy Fund funds to provide energy efficiency improvements loans for residential, commercial, and industrial facilities that are transferable to subsequent property owners.

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[266] RCW § 19.285.010.
[267] Wash. Rev. Code § 19.285.040(2)(a)(ii)-(iii) (2014).
[268] *See* Jacobson Decl.; Mark Z. Jacobson et al., *A 100% Wind, Water, Sunlight (WWS) All-sector Energy Plan for Washington State*, Renewable Energy 86 (2016) 75, 86.

        - PACE programs are administered by local governments and provide loans to property owners for energy improvements.[269] The financing mechanism allows owners to repay the loan with a 20-year term property tax-like assessment.[270] If the property owner sells their property before the end of the loan term, the loan can be paid off or transferred to the new property owner.[271]
    - Develop a fund specific to land use that allows landowners to apply for grants and incentives for sequestration activities and avoiding conversion.
        - Sequestration activities may include but are not limited to programs to encourage reforestation, improve forest management, reduce deforestation, conservation, and manage agricultural soils.[272]
    - Develop an environmental justice fund to assist non-homeowners in low-income and disadvantaged communities to make their homes more efficient and lower their energy costs.
    - Develop a fund for utilities transitioning to 100% renewable energy sources.
        - Increase the capacity factor of existing hydropower.[273][274]
        - Encourage the use of heat pumps and constant energy use.[275]
        - Infrastructure upgrades.
    - Develop plan to implement home and community energy storage and eliminate diesel and gas backup generators by 2030.[276]
    - Develop incentive and rebate programs, including but not limited to energy efficiency measures in buildings, including appliances and processes; weatherization; landlord efficiency investment;[277] efficient city street and building lighting; commercial and personal electric vehicles;

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[269] *See* State of Washington, Climate Legislative and Executive Workgroup, *Evaluation of Approaches to Reduce Greenhouse Gas Emissions in Washington State - Final Report* (October 14, 2013) ("Evaluation") at 35, available at http://www.governor.wa.gov/sites/default/files/documents/Task_4_Final_Report_10-13-2013.pdf.
[270] *Id.*
[271] *Id.*
[272] Managed agricultural soils have the potential store and reduce GHG emissions. Ecology should develop a grant program that encourages landowners to adopt recommended farming practices that result in GHG sequestration. Several of the recommended agricultural processes, including land application of biosolids and compost, have high accompanying costs. A grant program can help offset these costs to encourage better land practices while reducing overall GHG emissions. *See* Department of Ecology, *Soil Organic Carbon Storage (Sequestration) Principles and Management: Potential Role for Recycled Materials in Agricultural Soils of Washington State*, at vi (January 2015) available at vi, 68-9 https://fortress.wa.gov/ecy/publications/publications/1507005.pdf.
[273] Washington produces more hydropower than any other state. Currently, there is an oversupply of energy from other sources, causing hydropower to operate at less than its maximum capacity. Washington does not need to install any new hydropower plants. Instead, it must increase the capacity to utilize all current energy waste. *Id* at 79-80
[274] *Id.*
[275] *Id.*
[276] *See* Jacobsen et al. at 86.
[277] *Id.*

alternative and public transportation; and the development of hydrogen fuel vehicle fleets.

Work with the Washington Utilities and Transportation Commission (UTC)

Ecology has the authority to aid and assist the public utilities to ensure that its resources are developed in the public interest.[278] The health, environmental, and economic benefits of clean energy are in the public's interest. Ecology should work with UTC to adjust electricity rate schedules, remote long-term renewable energy contracts, eliminate coal and natural gas from electricity sector, reduce overall power production, upgrade electricity transmission lines, streamline renewable energy permitting, and develop other actions that will lead to a 100% renewable energy system by 2050. As such, Ecology should aid and assist the UTC with the following:

- Adjust the rate schedule to encourage energy use when wind, water, and solar power generation is abundant or during traditionally low-use times.[279]
- Require long-term, feed-in-tariff (FIT) contracts with providers of renewable energy at levelized rates for generation with optimal project siting requirements.
    - FITs are long-term fixed price renewable energy contracts between utilities and energy producers. They provide certainty to energy producers, and thus encourage the use of renewable energy. Currently, Washington utilizes a combination of net metering and a tax incentive mechanism. These policies can be replaced with a FIT.[280]
- Eliminate coal and natural gas from the electricity sector, including both in-state generation and electricity purchased from out-of-state.
- Require new permits from fossil fuel burning power plants that collectively result in a net power reduction of 17.2 GW by 2050.[281]
- Collaborate with the Western Interconnection states to develop plan to transition power lines to high-voltage direct current (HVDC) lines.
    - The current electricity transmission system utilizes high-voltage alternating current (HVAC) lines.[282] HVDC lines are more efficient and less expensive.[283] A network of HVDC lines reduces dependence on costly storage technologies to manage the intermittency of renewable energies.[284]

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[278] RCW § 43.21A.605
[279] *Id* at 87.
[280] *See* Evaluation at 36-7.
[281] Jacobson Decl, Exhibit P at 87.
[282] *See* A. Kalair et al., *Comparative Study of HVAC and HVDC Transmission Systems*, Renewable and Sustainable Energy Reviews 59 (2016) 1653-1675.
[283] *See* Alexander E. MacDonald et al., *Future Cost-competitive Electricity Systems and their Impact on US CO_2 Emissions*, Nature Clim. 6 (2016) 526-531, 527.
[284] *Id* at 526.

- Develop plan to streamline renewable energy permitting that will prioritize and fast track wind, water, and solar power generation and transmission lines permit applications;[285] incorporate environmental review process in permit process; and establish a fund from Clean Energy Fund funds for easy small scale solar and wind permitting.

4. Transportation

Transportation emissions represent 44% of overall GHG emissions in Washington.[286] Ecology must establish new transportation emissions standards to ensure the reduction of transportation emissions. Ecology can create a schedule to phase out fossil fuel vehicles and transition to 100% zero emissions by 2050. In the interim, Ecology should implement a program that encourages the use of low-carbon clean fuels. Additionally, Ecology should develop a plan to transition all public transportation fleets to 100% zero emissions by 2050. In an effort to slash transportation emissions, Ecology should consider the following:

- Implement a zero emissions vehicles (ZEV) goal that requires 50% of all vehicles sold by 2025 to be electric (zero-tailpipe emissions) with the elimination of fossil fuel-vehicle sales by 2050.[287]
- Implement a low carbon fuel standard, which includes a low-carbon full lifecycle analysis (LCFS)[288] to encourage the use of low-carbon clean fuels until fossil fuel vehicles are completely phased out.
    - A LCFS regulates fuel producers and importers selling gasoline and diesel fuel. It generates credits for lower carbon intensive transportation fuels, including ethanol, natural and bio-based gases, biodiesel, and electricity.[289]
- Enhance public transportation fleets and infrastructure:
    - Develop a plan to transition to 50% land and water electric vehicle fleets by 2025 and 100% by 2050
    - Provide assistance to local planning departments to develop a more robust and efficient public transportation infrastructure that encourages the use of public and alternative transportation.

(ii) Policies Ecology Should Recommend to the Legislature to Reduce the Burden on Ecology

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[285] *Id* at 85.
[286] *See* Department of Ecology, *Washington Greenhouse Gas Emission Reduction Limits: Report prepared under RCW 70.235.040,* at 8 available at https://fortress.wa.gov/ecy/publications/documents/1401006.pdf.
[287] *See* Evaluation at 31-2.
[288] *See* Department of Ecology,, *Path to a Low-carbon Economy: An Interim Plan to Address Washington's Greenhouse Gas Emissions* (December 2010) at 15, available at https://fortress.wa.gov/ecy/publications/publications/1001011.pdf.
[289]In 2010, Ecology analyzed the effectiveness of a LCFS and found that it "would reduce covered transportation GHG emissions by up to 12 percent above the policies the state currently has in place" and "provide a clear, long-term market for biofuels, electricity, and other alternative fuels in the state and promote investment in the infrastructure to deliver the low-carbon fuels of the future to Washington consumers."*Id.*

Ecology has a mandate to act now to reduce state GHG emissions. Ecology must do all it can to ensure the reduction of atmospheric CO_2 levels and ensure the protection of current and future generations. All of the policies listed in the previous section can be accomplished without additional Legislative approval. However, it may benefit the agency to make legislative recommendations, which, if enacted, could facilitate state efforts in mitigating the harmful effects of climate change. Regardless, the agency must act urgently and not wait for the Legislature to respond to recommendations. In an effort to collaboratively address climate change, Ecology should recommend the Legislature do the following:

1. Tax Credits
    - Implement a carbon tax, and use funds for clean energy transition incentives and rebates programs, environmental justice programs, forest and soil protection programs and adaptation plans.[290]
        - Carbon taxes can help policymakers, individuals, and firms prepare for GHG emissions costs by providing price certainty to the market.[291]
    - Create tax credits for emission reduction initiatives, including but not limited to green building initiatives, solar production projects, and industrial on-site wind, water, solar electricity generation.
    - Provide state funding to support on-site industrial wind, water, and solar electricity generation.

2. Greenhouse Gas Emission Limits and Renewable Energy Standard Targets based upon best available science.
    - Increase renewable energy targets for all sectors under RCW 19.285.040 to 80% by 2030 and 100% by 2050.[292]

3. Green Building Standards
    - Mandate that all new construction meet green building standards.
        - Washington Revised Code 39.35D currently mandates that projects receiving state funding must meet green building standards. The statute extends to all of Ecology's building projects. Ecology should recommend that this statute be expanded to all new construction. [293]

    - Provide tax exemptions for landlords' energy efficiency projects in rental properties.

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[290] *See* Evaluation at 29-30.
[291] *Id.*
[292] *See* Mark Z. Jacobson et al., *A 100% Wind, Water, Sunlight (WWS) All-sector Energy Plan for Washington State*, Renewable Energy 86 (2016) 75, 86.
[293] Wash. Rev. Code § 39.35D.030 (2011).

4. Electricity Sector

   - Require energy grid storage of 1.3 GWh by 2020.[294]
   - Impose fines for excess wind, water, and solar energy bleeding.

5. Incentives and Rebates
   - Pass enabling legislation to remove barriers to local Property Assessed Clean Energy (PACE)[295] programs administration that support energy conservation and renewable energy.[296]
   - Establish a fund for electric utilities, property owners, industries, and individuals to incorporate renewable energy technologies into electric sector. Projects may include but are not limited to heat pump utilization, solar panels, and electric vehicles.

There are many other policy options that Ecology can and should implement in order to reduce GHG emissions in a manner that protects the rights of young people and future generations.

VIII. CONCLUSION

We recognize that Ecology is currently under court order to finalize the Clean Air Rule by the end of the year. That order is in place in light of the urgency of the climate crisis and Ecology's historic inability to take regulatory action to reduce the state's GHG emissions. In light of the significant flaws in the existing draft of the Clean Air Rule that have been described above, we encourage you to work with us, as petitioners in the *Foster* case, on developing a rule that is based upon science, not politics.

We hereby incorporate by reference all hyperlinked and cited documents throughout these comments into the administrative record for this project. They are all publicly available. If you require PDF or hard copies of any of the hyperlinked or cited documents, please let us know and we will supply them; otherwise we will assume that Ecology can access them via the internet and will include them in the administrative record.

Respectfully Submitted,

s/ Andrea K. Rodgers	*s/ Julia Olson*
Andrea K. Rodgers	Julia Olson
Attorney	Executive Director & Chief Legal Counsel

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[294] *See* Jacobson et al. at 86.
[295] *See* State of Washington, Climate Legislative and Executive Workgroup, *Evaluation of Approaches to Reduce Greenhouse Gas Emissions in Washington State - Final Report* (October 14, 2013) ("Evaluation") at 35, available at http://www.governor.wa.gov/sites/default/files/documents/Task_4_Final_Report_10-13-2013.pdf.
[296] *Id.*

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EXHIBITS:

A. List of people and organizations that these comments are also submitted on behalf of

B. Petition for Rulemaking (June 17, 2014)

C. Ecology's Denial of Petition for Rulemaking (August 14, 2014)

D. *Foster, et al. v. Ecology*, No. 14-2-25295-1 SEA (King County Superior Court) (Order Affirming the Department of Ecology's Denial of Petition for Rulemaking) (Nov. 19, 2015)

E. *Foster, et al. v. Ecology*, No. 14-2-25295-1 SEA (King County Superior Court) (Order on Petitioners' Motion for Relief Under CR 60(b)) (May 16, 2016)

F. Washington Executive Order 14-04 (April 29, 2014)

G. Ecology December 2014 Report

H. Center for Biological Diversity, Petition to EPA for Additional Water Quality Criteria & Guidance Under Section 304 of the Clean Water Act, 33 U.S.C. § 1314, to Address Ocean Acidification (April 17, 2013)

I. Center for Biological Diversity Petition to EPA for Revised State Water Quality Standards for Marine pH Under the Clean Water Act, 33 U.S.C. § 1313(c)(4) (October 18, 2012)

J. *Svitak, et al. v. State*, King County Superior Court No. 69710-2-I (Amended Complaint) (filed May 18, 2011)

K. *Foster, et al. v. Ecology*, King County Superior Court No. 14-2-25295-1 (Department of Ecology's Response to June 23, 2015 Court Order) (filed August 7, 2015)

L. Dec. of Dr. Richard H. Gammon, *Foster v. Wash. Dep't of Ecology*, No. 14-2-25295-1 SEA 1 (Wash. Super. Ct. Aug. 24, 2015)

M. Dec. of Dr. Ove Hoegh-Guldberg, *Foster v. Wash. Dep't of Ecology*, No. 14-2-25295-1 SEA, 1 (Wash. Super. Ct. Aug. 24, 2015)

N. Declaration of Thomas Crowther, Ph.D.

O. Declaration of Dr. James Hansen

P. Declaration of Mark Jacobson

Q. Washington Emissions Data Compared to Science-Based Emissions Reductions

BEFORE THE WASHINGTON DEPARTMENT OF ECOLOGY

WASHINGTON DEPARTMENT OF ECOLOGY'S PROPOSED CLEAN AIR RULE	DECLARATION OF JAMES E. HANSEN, PHD, IN SUPPORT OF WESTERN ENVIRONMENTAL LAW CENTER AND OUR CHILDREN'S TRUST'S COMMENTS ON PROPOSED CLEAN AIR RULE

I, DR. JAMES E. HANSEN, hereby declare as follows:

1. I make and offer this declaration as an expert in the field of climate science.

2. I am a U.S. citizen, an Adjunct Professor at Columbia University's Earth Institute, and Director of the Climate Science, Awareness and Solutions program at the Earth Institute, Columbia University. I am also the immediate past Director of the NASA Goddard Institute for Space Studies and a member of the United States National Academy of Sciences.

I have testified before the United States Senate and House of Representatives on many occasions, and in court on several occasions, in support of efforts to reduce reliance on carbon-intense energy from fossil fuels and rapidly transition to carbon-free energy.

3. My training is in physics and astronomy, with early research on the clouds of Venus. Since the late 1970s, I have focused my research on Earth's climate, especially human-made climate change. Most recently, I have dedicated significant effort towards outlining the actions that must be undertaken by communities, states, the U.S. Government, and others, in order to preserve a viable climate system for young people, future generations, and other life on Earth. For the Department of Ecology's more complete reference, I have attached my full CV as Exhibit 1 to this declaration.

4. In my opinion, the nature of state, federal, and international climate and energy policy is at-best schizophrenic, if not suicidal,.

5. On the one hand, governments have recognized a fundamental duty to protect the public resources on which we depend; to safeguard our lives and property; to secure the blessings of liberty; to ensure equal protection under the law for "ourselves and our posterity"; and, pursuant

to the United Nations Framework Convention on Climate Change (UNFCCC), to "protect the climate system for present and future generations."

6. On the other hand, governments around the world continue to permit and otherwise support industry's efforts to exploit fully our reserves of gas, coal, and oil, even in the face of increasing overwhelming evidence that our continued fossil fuel dependency is driving the atmospheric concentration of carbon dioxide (CO_2) far beyond that in human experience, and constitutes one of the greatest threats to human civilization and nature alike.

7. These antinomies cannot be explained away as the product of ignorance. Governments have known for decades that the continued burning of coal, oil and natural gas causes global warming and risks dangerous and uncontrollable destabilization of the planet's climate system, on which young people and future generations depend.

8. Moreover, governments have, during the last half century, promoted the exploitation and consumption of fossil fuels in myriad ways. For example, the actions taken and emission reduction targets proposed by the Washington state government in the name of fighting climate change serve only to legalize dangerous CO_2 pollution and further increase the atmospheric concentrations of CO_2.

9. It is now clear, as the relevant scientific community has established for some time, that continued high CO_2 emissions from fossil fuel burning will further disrupt Earth's climate system, and that, in turn, will impose profound and mounting risks of ecological, economic and social collapse. In my view, government actions and inactions that cause or contribute to those emissions violate the fundamental and inalieanable rights of youth and future generations. Those violated rights include the right to life, the right to liberty, the right to property, the right to equal

protection under the law, the right to government protection of public trust resources, and the right to retain a fighting chance to preserve a habitable climate system.

10. Here, then, I will address the fundamental context in which those fundamental rights violations arise. That context includes Earth's present and growing energy imbalance and the still real, but highly time-limited, opportunity to rapidly phase-down CO_2 emissions, restore energy balance, and stabilize the climate system.

11. The Washington Department of Ecology will find a more detailed treatment of these points, with supporting explanatory material and data, in two recent papers of which I am the lead author.

12. The first, Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature, was published in late 2013, in conjunction with 17 colleagues. In that study we established that continued fossil fuel burning up to even 2°C above the preindustrial level[1] likely would cause large climate change with disastrous and irreversible consequences, so that actions to rapidly phase out CO_2 emissions are urgently needed to reduce the atmospheric CO_2 concentration to no more than 350ppm and restore Earth's energy balance. I have attached *Dangerous Climate Change* hereto as Exhibit 2,[2] and I hereby incorporate by reference, into this declaration, its analyses and conclusions.

13. The second, Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous, was

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

2 Published by PLOS One (Dec. 3, 2013) and available at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0081648

published this month in conjunction with 16 colleagues. In it we conclude that, if CO_2 emissions are allowed such that energy is continuously pumped at a high rate into the ocean, then multi-meter sea level rise will become practically unavoidable, with consequences that may threaten the very fabric of civilization. I have attached *Ice Melt, Sea Level Rise and Superstorms* hereto as Exhibit 3,[3] and hereby incorporate by reference into this declaration its analyses and conclusions.

I. PRESENT AND LOOMING CLIMATE CRISES, AND A PATH TO STABILITY

14. As indicated above, our late-2013 study provides a detailed treatment of our present predicament and the route that must be taken to sufficiently reduce atmospheric CO_2 to preserve a habitable climate system. *See* Exhibit 2. Our most recent work, establishing that nonlinear melting of Earth's major ice sheets is likely within a century, among other things, if fossil fuel emissions continue unabated, adds an additional element of immediacy to what, for too long, has been treated in practical terms as, at best, a distant but growing complication. *See* Exhibit 3.

15. I outline and summarize these matters here, before proceeding to a further explanation of them.

16. **First**: Human burning of fossil fuels has disrupted Earth's energy balance. In response, the planet is heating up – with no end in sight, unless we alter our present path. Atmospheric CO_2 concentration, for example, is now at its highest level in 3 million years, and global surface temperatures now have reached the prior maximum of the Holocene era, the period of relatively moderate climate that, over the last 10,000 years, enabled civilization to develop.

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3 *See also*: http://www.atmos-chem-phys-discuss.net/15/20059/2015/acpd-15-20059-2015.pdf

17. **Second**: We are observing impacts of the relatively small amount of warming that has already occurred, and these constitute harbingers of far more dangerous change to come. We can discuss the observable consequences, and their implications, but the key point is that, if unabated, continued carbon emissions will initiate dynamic climate change and effects that spin out of human control, as the planet's energy imbalance triggers amplifying feedbacks and the climate and biological systems pass critical tipping points. Sea-level rise provides a key metric here.

18. **Third**: There is still time and opportunity to preserve a habitable climate system -- if we pursue a rational course. I will outline the glide path that we think remains feasible, though further delay in taking effective action will consign that effort to failure. Objectively, then, the situation is urgent and what Ecology and other decision-makers do, or do not do, today to reduce carbon pollution matters immensely.

II. OUR PLANET IS NOW OUT OF ENERGY BALANCE

19. In Chart 1, we show global fossil fuel CO_2 emissions on an annual basis from the burning of coal, oil, and natural gas, and from cement production and flaring, along with the total emissions from these major sources. Although it is more than twenty years since 170 nations agreed to limit fossil fuel emissions in order to avoid dangerous human-made climate change, the stark reality – as illustrated here – is that global emissions have accelerated. Specifically, the growth rate of fossil fuel emissions increased from 1.5%/year during 1973–2000 to 2.6%/year in 2000–2014 (Chart 1(a)), due in the main to increased utilization of coal, oil, gas and cement (Chart 1(b)).

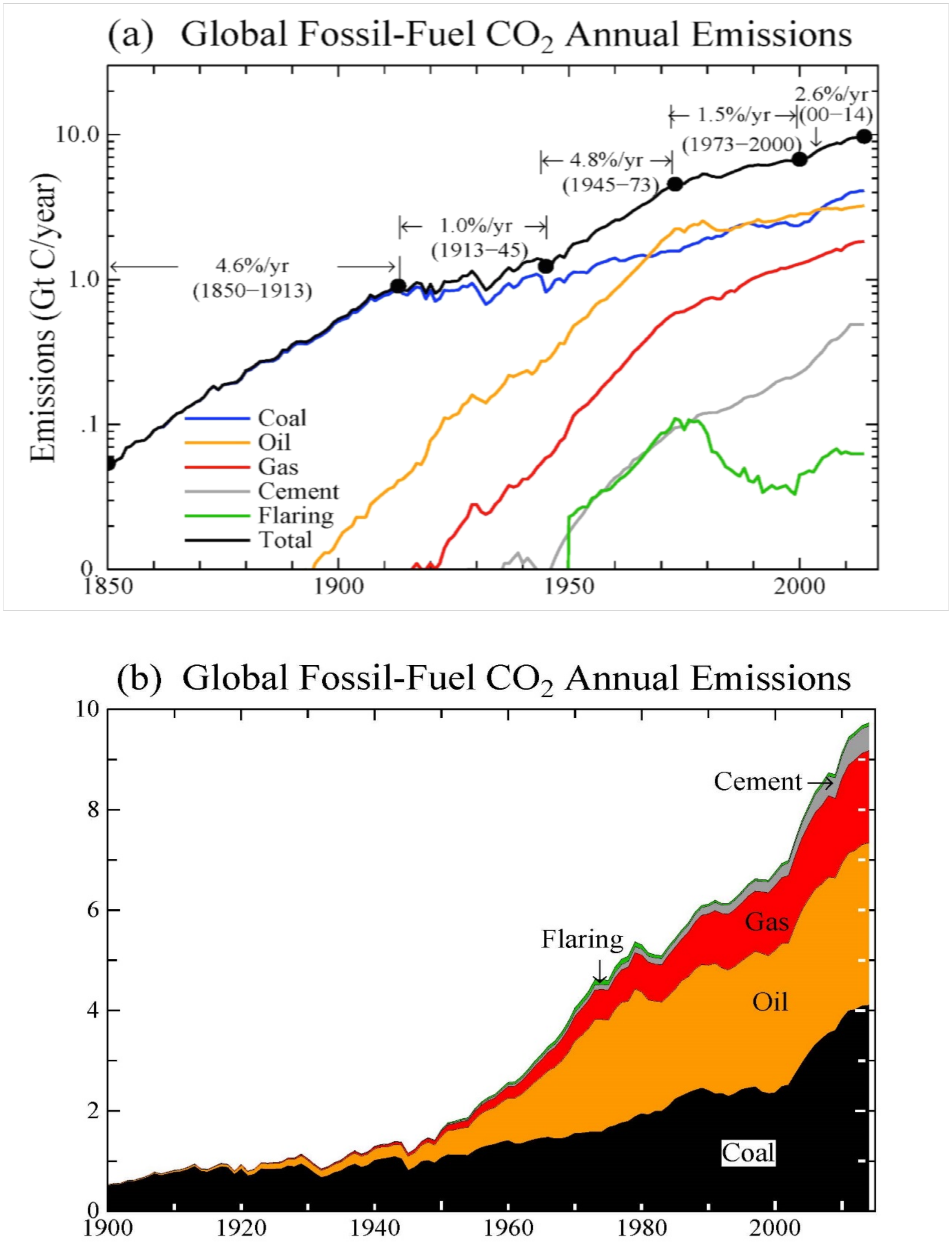

Chart 1: **CO_2 Annual Emissions From Fossil Fuel Use And Cement Manufacture**
Source: *Dangerous Climate Change* (Exhibit 2 to this Declaration, at Fig. 1), updated through 2014 from http://www.columbia.edu/~mhs119/CO2Emissions/.

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

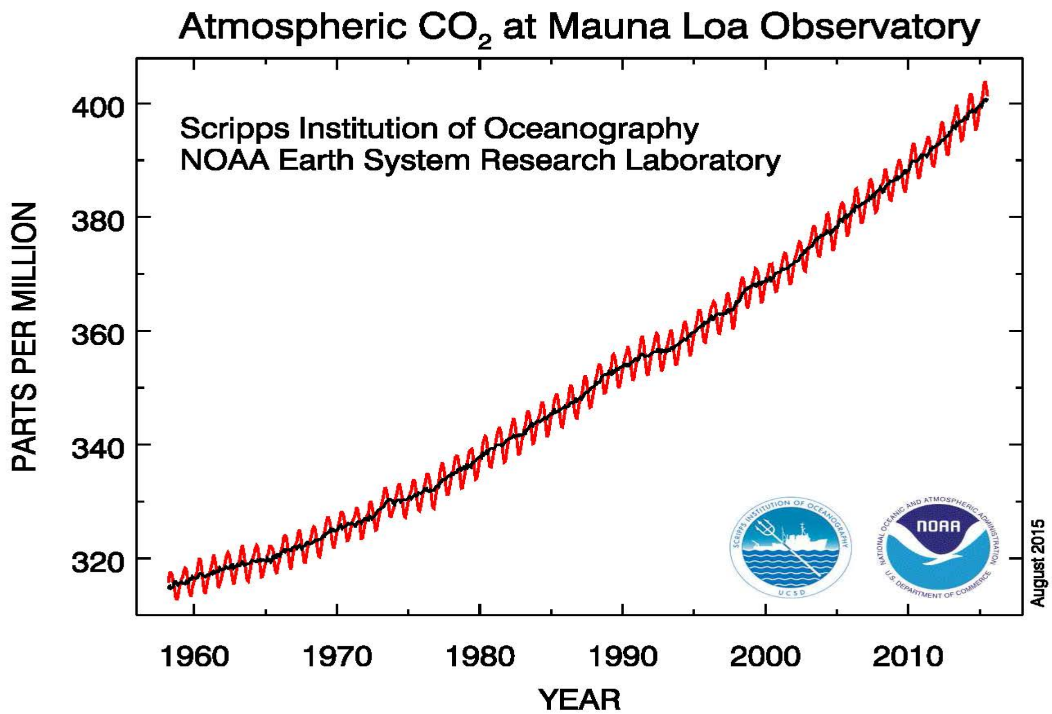

Chart 2: From Noaa's Earth System Research Laboratory
at http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full.

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

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

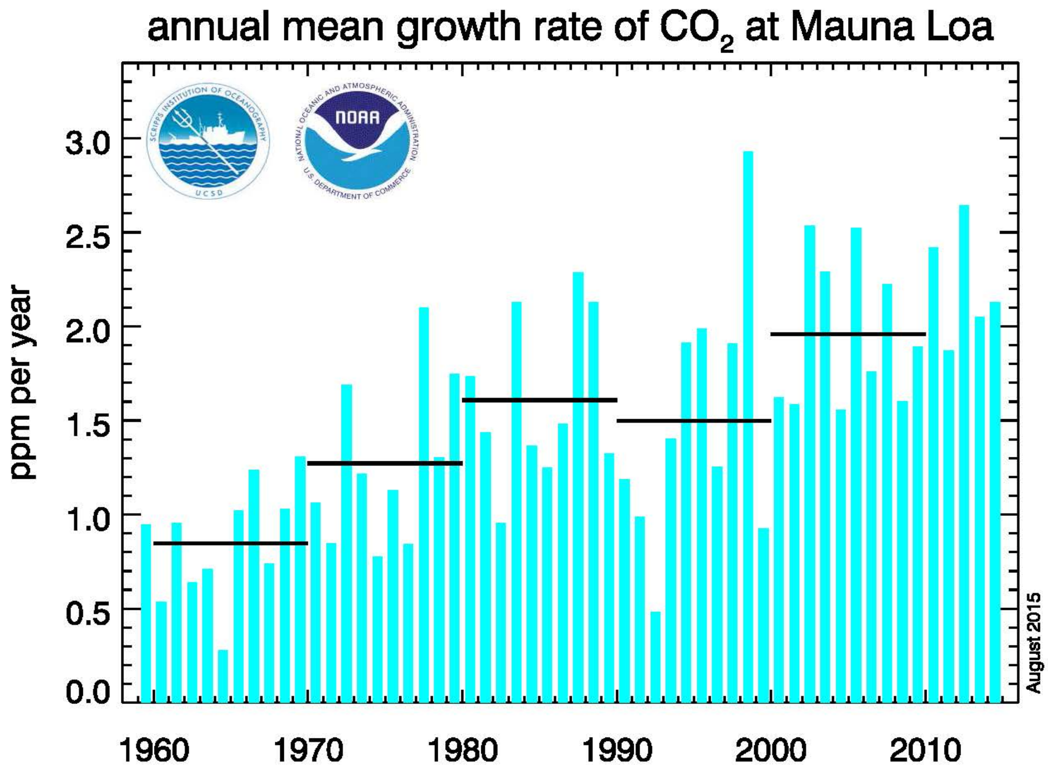

Chart 3: From Noaa's Earth System Research Laboratory
at http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_growth.

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

23. In point of fact, warming of Earth caused by the increasingly thick CO_2 "blanket" persisted even during the recent five-year solar minimum from 2005-2010. Had changes in insolation been the dominant forcing, the planet would have had a negative energy balance in that period, when solar irradiance was at its lowest level in the period of accurate data, i.e., since the 1970s. Instead, even though much of the greenhouse gas forcing had been expended in causing observed 1°C global warming to date, the residual positive forcing from CO_2 emissions

overwhelmed the negative solar. This illustrates, unequivocally, that it is human activity, and not the sun, that is the dominant driver of recent climate change.

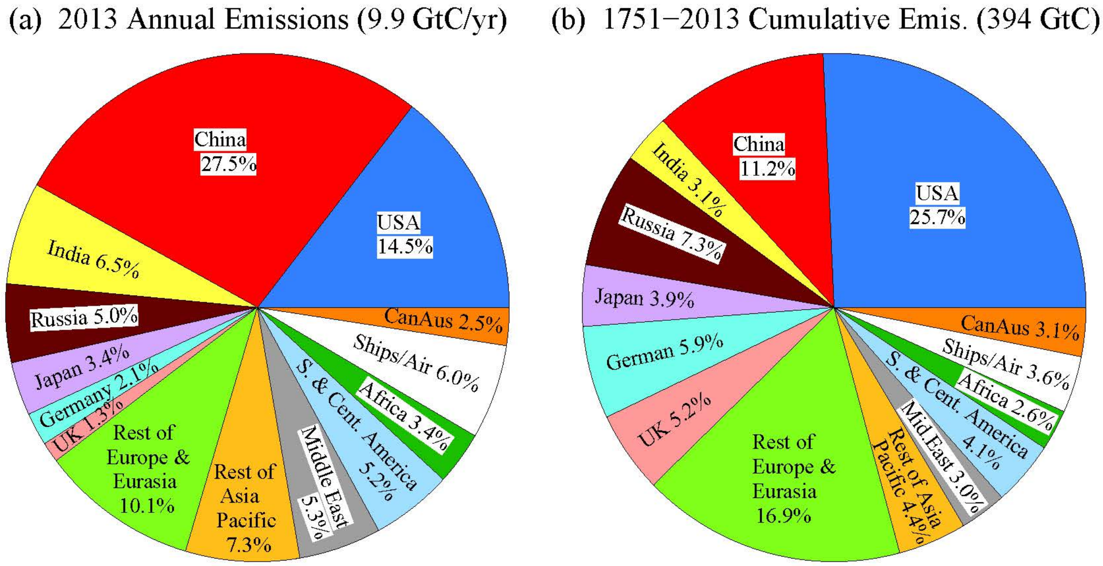

Chart 4: Fossil Fuel CO_2 Emissions
Source: *Dangerous Climate Change* (Exhibit 2 to this Declaration at Fig. 11)
updated through 2013 at http://www.columbia.edu/~mhs119/CO2Emissions/Emis_moreFigs/.

24. In light of the long residence time of CO_2 following its injection into the atmosphere, it is a sovereign state's sum total of its emissions that is the more proper measure of its responsibility for already-realized and latent climate change. *See* Chart 4 (b) (right side). Here, I believe that a further word about the atmospheric residence time of CO_2 is in order, and we can do that with the aid of Chart 5 (left side).

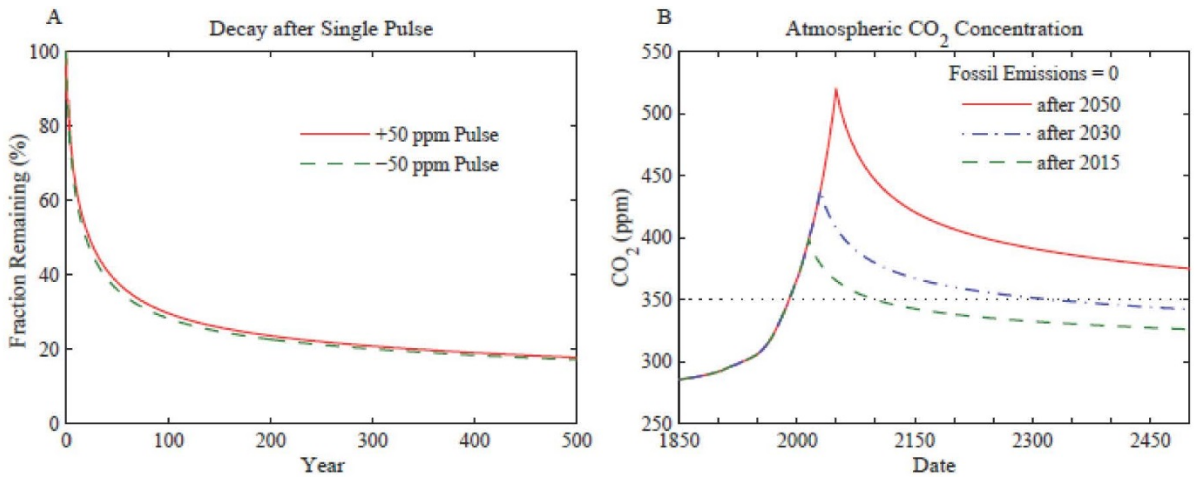

Chart 5: Decay Of Atmospheric Co_2 Perturbations
Source: *Dangerous Climate Change* (Exhibit 2 to this Declaration at Fig. 4). (A) Instantaneous injection or extraction of CO_2 with initial conditions at equilibrium. (B) Fossil fuel emissions terminate at the end of 2015, 2030, or 2050 and land use emissions terminate after 2015 in all three cases, i.e., thereafter there is no net deforestation.

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

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

27. It is in part for this reason – the atmospheric persistence of CO_2 – that our national contribution to the problem is so large. Moreover, we can observe that, as compared with that of other major CO_2-emitting nations, our national contribution to the global climate crisis is not only

largest in absolute amount (Chart 4b), it dwarfs the contributions of the most populous nations on a per capita basis. Chart 6.

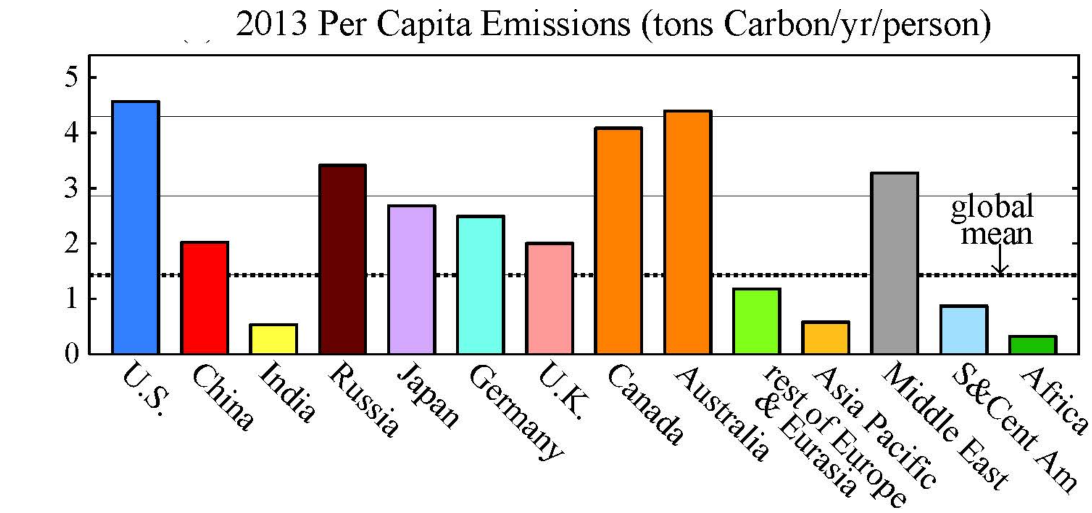

Chart 6: **Cumulative Per Capita Carbon Dioxide Emissions**
Source: www.columbia.edu/~mhs119/YoungPeople/.

28. Turning, now to Chart 7, we see the upward march of recent average global surface temperature.

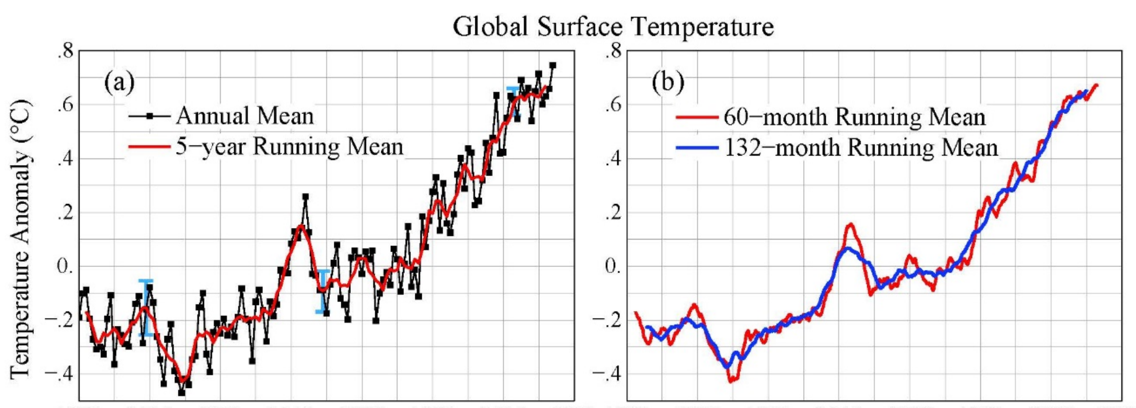

Chart 7: **Global Surface Temperature Anomaly (60-Month And 132-Month Running Means) With A Base Period Of 1951-1980**
Source: *Dangerous Climate Change* (Exhibit 2 to this Declaration at Fig. 3), updated at [http://www.columbia.edu/~mhs119/Temperature/.](http://www.columbia.edu/~mhs119/Temperature/)

29. Earth has now warmed about 1°C above the pre-industrial level. That is now close to, and probably slightly above, the prior maximum of the Holocene era – the period of relatively stable climate over the last 10,000 years that has enabled human civilization to develop.

30. The warming increases Earth's radiation to space, thus reducing Earth's energy imbalance. However, because of the ocean's great thermal inertia, it requires centuries for the climate system to reach a new equilibrium consistent with a changed atmospheric composition. The planet's energy imbalance confirms that substantial additional warming is "in the pipeline". That energy imbalance is now measured by an international fleet of more than 3000 submersible floats that plumb the depths of the world's ocean measuring the increasing heat content.

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

32. We can turn now to Chart 8.

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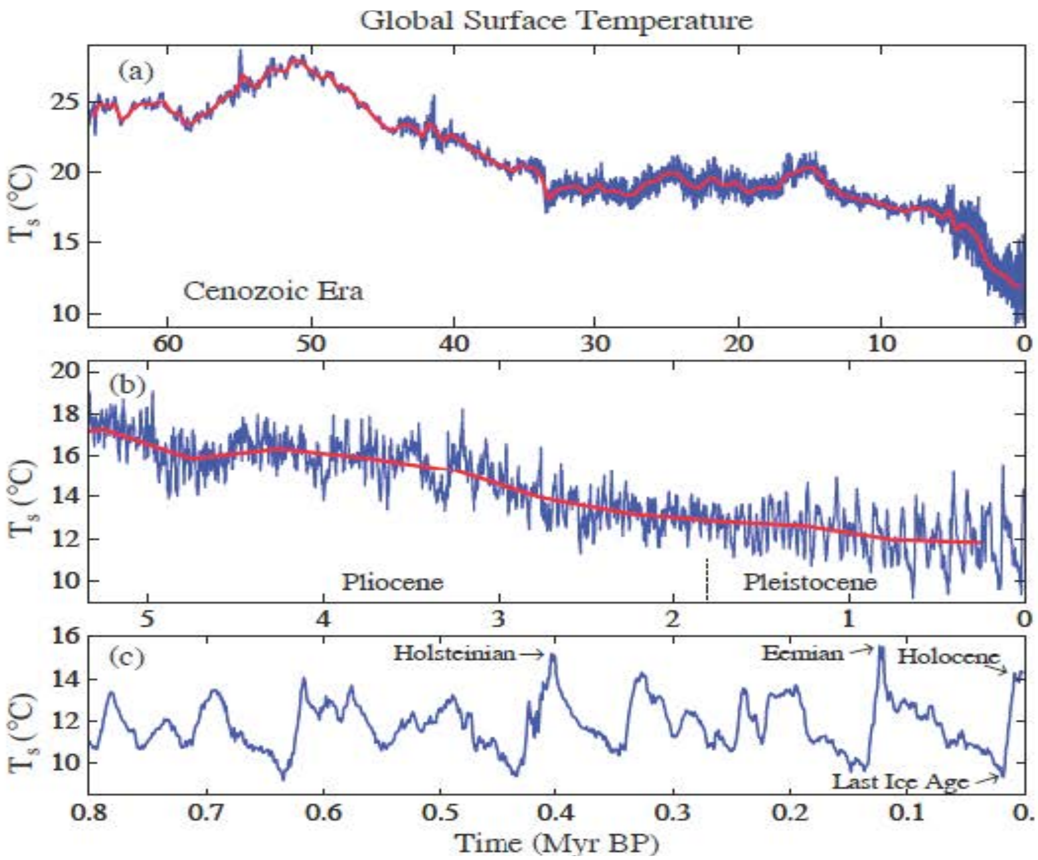

Chart 8: **Surface Temperature Estimate for the Past 65.5 Myr, Including An Expanded Time Scale for (B) The Pliocene and Pleistocene and (C) The Past 800 000 Years**
Source: J. Hansen, et al, *Climate Sensitivity, Sea level and Atmospheric Carbon Dioxide*, Phil Trans R Soc A (2013), Fig. 4.

33. Here, we summarize the average global surface temperature record of the last 65 million years. This record is based on high-resolution ice core data covering the most recent several hundred thousand years, and ocean cores on time scales of millions of years. It provides us with insight as to global temperature sensitivity to external forcings such as added CO_2, and sea level sensitivity to global temperature. It also provides quantitative information about so-called “slow” feedback processes – such as melting ice sheets and lessened surface reflectivity attributable to darker surfaces resulting from melting ice sheets and reduced area of ice.

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

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

36. I conclude that the present level of CO_2 and its warming, both realized and latent, is already in the dangerous zone. Indeed, we are now in a period of overshoot, with early consequences that are already highly threatening and that will rise to unbearable unless action is taken without delay to restore energy balance at a lower atmospheric CO_2 amount. We can turn now to a brief review of the increasingly unacceptable, but still avoidable, consequences.

III. UNABATED EMISSIONS MAY DEVASTATE OUR COASTS, CIVILIZATION AND NATURE AS WE KNOW IT

37. I will start with the ocean, in light of our most recent research.

38. While I have postulated previously that major ice sheet disintegration and resulting sea level rise is likely to be nonlinear in the event of continued high fossil fuel impacts, my concern had been based largely on heuristic grounds. Now, utilizing multiple lines of evidence –

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

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

40. The rising seas will combine, in places, including especially in the North Atlantic region, with growing storminess to further threaten low-lying and other coastal regions. The phenomenon is a function not only of a warming atmosphere that renders additional water and energy available to any developing weather event, but also because melting ice sheets increase sea level pressure at middle (relative to polar) latitudes and thereby strengthen temperature gradients, supercharging storms with baroclinic sources. This growing climate chaos will increasingly lash regions within the storms' reach, including much of the North Atlantic seaboard. Persons within these regions who lack discretionary resources to flee and rebuild, or else to relocate, predictably will be among those most severely harmed.

41. Persons situated in low-lying regions therefore will predictably be disproportionately impacted by unarrested global warming. So too will future generations be severely harmed. Our children and their progeny will be the ones to experience the full impact of slow feedbacks that, only now, are coming into play, including ice sheet disintegration, as well as changes in the global vegetation distribution, melting of permafrost, and possible release of methane from hydrates on continental shelves. Indeed, our sovereign governments are on the verge of imposing an overwhelming burden – intergenerational injustice in the extreme – upon young people and future generations who stand to inherit a climate system that is not at all conducive to their well-being or survival, through no fault of their own.

42. In the light of this and related information, we have concluded that humanity faces "nearly certainty of eventual sea level rise of at least . . . 5-9 m if fossil fuel emissions continue on a business-as-usual course." *See* Exhibit 3 at pdf page 31. Much of the U.S. eastern seaboard, low-lying western U.S[6] cities, as well as low-lying areas of Europe, the Indian sub-continent, and the Far East, would then be submerged. *See* Chart 9.

43. It is estimated, for example, that sea level rise of "only" 10 feet (approximately 3 meters) will inundate over 4,000 acres (and over 3,000 homes) in Seattle, nearly 3,000 acres (and over 13,000 homes) in San Francisco, and over 4,000 acres (and nearly 10,000 homes) in San Diego.

44. Much of coastal Washington is at risk of being submerged, perhaps in as little as several decades from now – and thus lost irretrievably, at least for millennia, absent serious action to phase out fossil fuel emissions.

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[6] *See* Climate Central's "Surging Seas" project at http://sealevel.climatecentral.org/ .

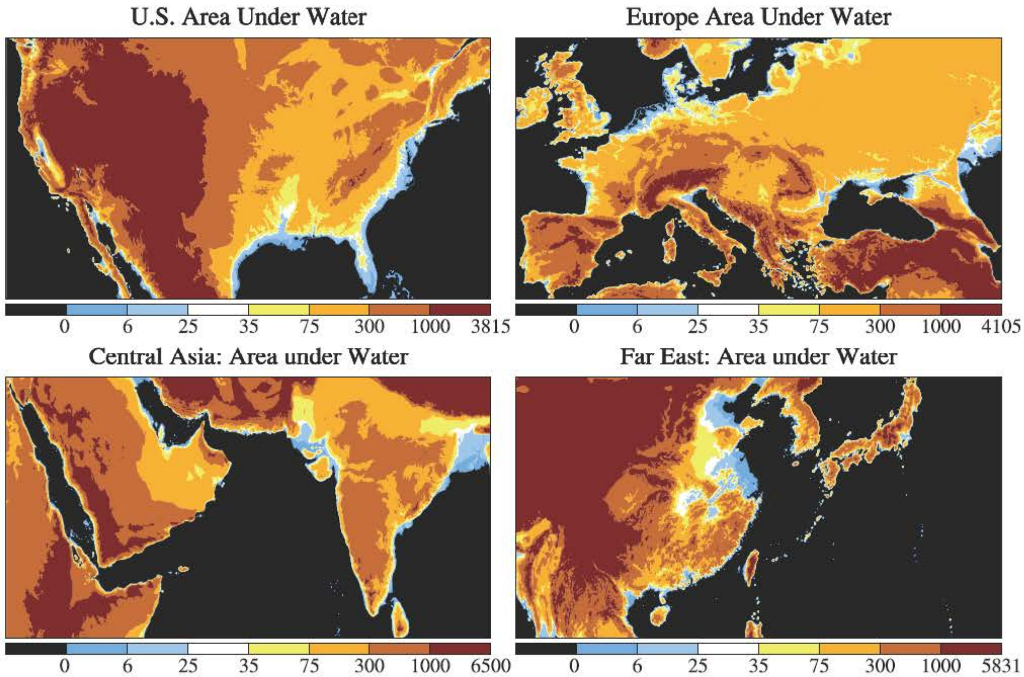

Chart 9: **Areas (Light And Dark Blue) That Nominally Would Be Under Water For 6 And 25 M Sea Level Rise**
Source: Climate Science, Awareness, and Solutions, Earth Institute, Columbia University (2015).

45. That order of sea level rise would result in the loss of hundreds of historical coastal cities worldwide, with incalculable economic consequences. It would also create hundreds of millions of global warming refugees from highly populated low-lying areas, and thus likely cause or exacerbate major international conflicts.[7]

46. To avoid such a calamity, sea level rise must be recognized as a key limit on any conceivably allowable human-made climate forcing and atmospheric CO_2 concentration, with

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[7] In addition, strong temperature gradients caused by ice melt freshening is likely to increase baroclinicity and provide energy for more severe weather events, including in the North Atlantic. This set of circumstances will drive the powerful superstorms of our future. Some of these impacts are beginning to occur sooner in the real world than in our climate model. *See* Exhibit 3 at pdf 31.

fossil fuel emissions and land use changes constrained accordingly.[8] As discussed, ice sheet melting has now commenced even though global warming to date measures "only" 0.9°C above the pre-industrial period. This is consistent with the relevant paleoclimate evidence showing a multi-meter rise in sea level in the late Eemian period, approximately 125K years ago, when temperature was at most ~2°C warmer than pre-industrial climate (at most ~1°C warmer than today). This, in itself, and quite apart from the additional harm to terrestrial systems that must also be considered, implies that national and international goals and targets that aim to limit global warming to no more than 2°C run an unacceptably high risk of global catastrophe.

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

48. Upon cessation of ice sheet disintegration and freshwater discharge, global temperature will recover – with the time period for such recovery depending on the amount of ice melt (and sea level rise), and with geographical, geophysical and oceanic circulation factors detailed in our recent study. *See* Exhibit 3 at pdf 11.

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[8] This is so, as we wrote in "Ice Melt, Sea Level Rise and Superstorms," Exhibit 3 at pdf 32, in light of the "extreme sensitivity of sea level to ocean warming and the devastating economic and humanitarian impacts of a multi-meter sea level rise."

49. With respect to other important natural and human systems, to which I will now turn, the impacts of global warming – including the renewed warming – will depend in part on the magnitude of Earth's energy imbalance, and that, in turn, will be controlled by the level of excess atmospheric CO_2. As I have noted already, global warming to date measures "only" 1°C above the pre-industrial period, and yet, that level of warming has already begun to have a widespread effect on natural and human systems.

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

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

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

53. World health experts have concluded with "very high confidence" that climate change already contributes to the global burden of disease and premature death with expansion of

infectious disease vectors. Increasing climate variability is being examined as a possible contributor to the expansion of Ebola.

54. Subtropical climate belts have expanded, contributing to more intense droughts, summer heat waves, and devastating wildfires. Further, summer mega-heat-waves, such as those in Europe in 2003, the Moscow area in 2010, Texas and Oklahoma in 2011, Greenland in 2012, Australia in 2013, *Australia and California in 2014, and India, France and Spain this year (2015),* have become more widespread.[9] The probability of such extreme heat events has increased by several times because of global warming, and the probability will increase even further if fossil fuel emissions continue to be permitted, so that global warming becomes locked in or rendered increasingly severe.

55. Wildfire frequency and magnitude, such as those that raged throughout the state of Washington in August 2015, will climb in ensuing decades if CO_2 emissions are not rapidly phased out, but I observe here, on the basis of research that colleagues and I have recently completed, that such infernos may not prove to be the most severe foreseeable climate-driven calamity confronting civilization in coming decades.

56. For example, acidification stemming from ocean uptake of a portion of increased atmospheric CO_2 will increasingly disrupt coral reef ecosystem health, with potentially devastating impacts to certain nations and communities. Inland, fresh water security will be

[9] Climate researchers in the Northwest consider Oregon's recent heat and dry spell to be consistent with these trends, with the month of June, 2015 being said to be the warmest on record in much of the state. *See* Oregon Climate Service at http://ocs.oregonstate.edu/ . In general, however, local observations of climate (heat) extremes are illustrative of what will occur with the increasing atmospheric CO_2 concentration, but I will caution that other, more stochastic, variables usually will be in play as well.

compromised, due to the effects of receding mountain glaciers and snowpack on seasonal freshwater availability of major rivers.

57. With respect to rising temperature, global warming of recent decades has been sufficient to shift the bell curve distribution of temperature anomalies (in units of standard deviation) above the climatological base period of 1951-1980 for the aggregate areas of the northern hemisphere as well as that of the southern hemisphere. This is true for most large sub-hemisphere geographical regions as well.

58. For instance, the summer bell curves for the United States and North and Central Europe are shifted more than one standard deviation (1σ).[10] That shift is enough to increase the frequency of summers warmer than $+2\sigma$ from less than 1 percent to greater than 10 percent. Even larger temperature distribution shifts are observed for the period 2005-2015 in China, India, the Mediterranean, the Middle East, the Sahara and Sahel, South-east Asia, and the African rainforest. Within the continental United States, large summer warming has been experienced in much of the western region and, to a somewhat lesser but still significant extent, along the eastern seaboard. The large warming and dry conditions over the period exacerbated wildfire in the western United States, and I anticipate worse to come with continued global warming.

59. Other practical consequences include lost work capacity. Agricultural and construction workers in tropical developing countries may be most exposed to increasing heat stress and stroke, but workers in places such as Southeast and Southwest United States and Eastern China will also be affected by increasing temperature and, in places, increased absolute humidity.[11]

[10] The shift in the winter is only about half of a standard deviation.

[11] Generally, as global warming increases, climatologically wet regions, such as the American Southeast, tend to get wetter, and dry regions, such as the American Southwest, tend to get hotter and drier.

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

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

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

63. High global surface temperatures have been recorded previously, in the age of mammals, with some successful adaptation through evolution of higher surface-area-to-mass ratio body

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

64. All of which brings me to my third point.

IV. RESTORATION OF OUR CLIMATE SYSTEM, AND SO PROTECTION OF OUR FUTURE, IS STILL POSSIBLE, BUT WE MUST ACT WITH REASON, COURAGE, AND NO FURTHER DELAY

65. As I indicated above, the energy imbalance of Earth is about 0.6 W/m2. In the light of that imbalance, colleagues and I have calculated the level to which atmospheric CO_2 must be drawn down in order to increase Earth's heat radiation to space by the same amount and thus restore energy balance – the fundamental requirement to stabilize climate and avoid further dangerous warming.

66. The measured energy imbalance indicates that CO_2 must be reduced to a level below 350 ppm, assuming that the net of other human-made climate forcings remains at today's level. Specification now of a CO_2 target more precise than <350 ppm is difficult due to uncertain future changes of radiative forcing from other gases, aerosols and surface albedo, but greater precision should be feasible during the time that it takes to turn around CO_2 growth and approach the initial 350 ppm target.

67. Let us return, for a moment, to Chart 5, so as to consider again the question of delay. On the left side of the chart, the long-residence time for atmospheric CO_2 is illustrated. It is reflected

in the length of time it would take to return CO_2 to lower concentrations even if, as indicated on the right side of the chart, fossil fuel emissions were to cease entirely.

68. Of course, an abrupt cessation of all CO_2 emissions, whether this year or in 2030, is unrealistic. Industry, other business, and consumers all need time to retool and reinvest in emission-free options to fossil fuels.

69. Accordingly, we have evaluated emissions reduction scenarios to devise the path that is both technically and economically feasible, while being sufficiently rigorous to constrain the period of "carbon overshoot" and avoid calamitous consequences (greatly accelerated warming, ecosystem collapse, and widespread species extermination). *See* Chart 10.

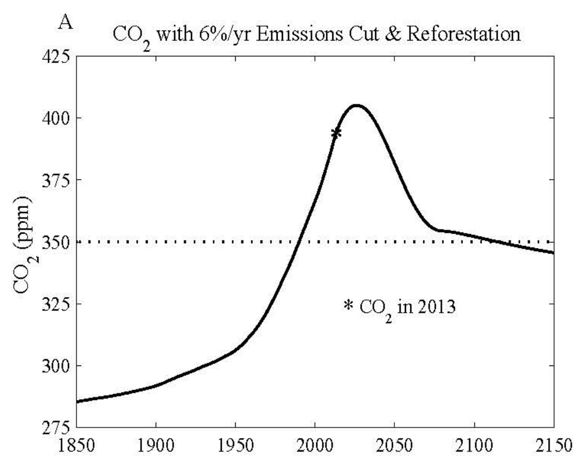

Chart 10: **Atmospheric CO_2 If Fossil Fuel Emissions Are Reduced.**
(A) 6% Annual Cut Begins In 2013 and 100 GRC Reforestation Drawdown Occurs In 2031-2080, (B) Effect Of Delaying Onset Of Emission Reductions.
Source: *Dangerous Climate Change* (Exhibit 2 to this Declaration at Fig. 5).

70. Our analysis prescribes a glide path towards achieving energy balance by the end of the century. It is characterized by large, long-term global emissions reductions (of approximately 7 percent annually if commenced this year, 8 percent if commenced in 2017, and 8.5 percent if

commenced in 2018),[12] coupled with programs to limit and reverse land use emissions via reforestation and improved agricultural and forestry practices (drawing down approximately 100 GtC globally by the year 2100).

71. These actions could achieve the goal of restoring the atmosphere to approximately 350 ppm within this century if the plan were commenced without delay, and then adhered to. As I have indicated, such action is minimally needed to restore earth's energy balance, preserve the planet's climate system, and avert irretrievable damage to human and natural systems – including agriculture, ocean fisheries, and fresh water supply – on which civilization depends. However, consistent with the abrupt phase out scenarios discussed in the prior paragraph, if rapid annual emissions reductions are delayed until 2030, then the global temperature will remain more than 1°C higher than preindustrial levels for about 400 years. Were the emissions cessation only to commence after 40 years, then the atmosphere would not return to 350 ppm CO_2 for nearly 1000 years. Overshooting the safe level of atmospheric CO_2 and the safe range of global ambient temperature for anything approaching these periods will consign succeeding generations to a vastly different, less hospitable planet.

72. Considered another way, the required rate of emissions reduction would have been about 3.5% per year if reductions had started in 2005 and continued annually thereafter, while the required rate of reduction, if commenced in 2020, will be approximately 15% per year.

[12] This path assumes that global emissions are held fixed from 2014 (the last year of available historical data) until and including the year before the cuts begin. If we instead assume 2 percent per year emissions increases over the same time periods (for consistency with the scenario in Exhibit 2 to this Declaration), then the required minimum annual reductions will be marginally higher, at 7.5, 8.2, and 9 percent.

Accordingly, the dominant factor is the date at which fossil fuel emission phase out begins, again presuming the rate of annual emissions reductions thereafter are sustained.

V. THE "COMMITMENTS" MADE AT COP-21

73. The largely precatory agreement secured at COP-21 neither resolves nor ameliorates the unfolding crisis of dangerous, human-caused disruption of the climate system.

74. By the time COP-21 commenced on November 30, 2015, most nations – including all of the so-called "G20 nations"[13] responsible for nearly 80% of global emissions – had presented their "intended nationally determined contributions" ("pledges") to the UNFCCC. The United States, for example, submitted its pledge on March 31, 2015.

75. Independent analysis of the major nations' pledges heading into COP-21 established that, when taken together, there remained a large gap between the aggregate emissions that would be allowed (even assuming that pledges constituted binding commitments) and the level of action, in terms of actual emissions reductions, required to hold global warming below 2˚C.[14] The United States' pledge had been independently assessed as "not yet consistent with limiting warming to below 2°C *unless other countries make much deeper reductions and comparably greater effort than the USA*."[15]

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[13] The G20 is comprised of Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, and the United States.

[14] *See*, for example, Climate Action Tracker, Update: G20 – all INDCs in, but large Gap remains, Nov. 13, 2015, available at http://climateactiontracker.org/assets/publications/briefing_papers/G20_gap.pdf.

[15] Climate Action Tracker, USA Assessment (emphasis added) (indicating that the US climate plans are "at the least ambitious end of what would be a fair contribution" and that "if all countries would choose the least ambitious end of their respective range, global temperature increase would be well above 2˚C."), updated Sept. 4, 2015, available at http://climateactiontracker.org/countries/usa.html.

76. It was therefore unsurprising that, by its own terms, the Paris Agreement cited the Parties' "serious concern" with "the significant gap between the aggregate effect of Parties' mitigation pledges" and what is required to preserve the planet. *See* Paris Agreement, FCCC/CP/2015/L.9/Rev.1, at 2.[16]

77. In that regard, the Paris Agreement properly "*[t]akes note* of the synthesis report on the aggregate effect of intended nationally determined contributions." *Id*. at 4. That synthesis report, in turn, states, among other things, that even if the nations' announced targets were to be "exactly met" then "global emissions are *likely to increase until 2030*." *See* Synthesis Report, FCCC/CP/2015/7, at 41, par. 193 (emphasis added).[17]

78. Based on my experience and applying my scientific judgment, and consistent with the judgment of numerous other climate scientists, it is clearly that allowing global CO_2 emissions to *increase* for another 15 years would likely consign future generations to a far different, largely unrecognizable, planet, one marked in vast reaches by unbearable summer heat, ecological collapse, species extinction, widespread famine, coastal cities lost to rising seas, mass human migration, and riven national and international conflict. That list is but a start of what probably will occur. Such an unappealing, but increasingly likely, scenario is outlined above. In that light, then, the Parties to the Paris Agreement were understated in noting "*with concern* that the estimated aggregate greenhouse gas emission levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within least-cost 2˚C scenarios." Paris Agreement at 3, par. 17 (emphasis added).

79. Also as discussed above, based on multiple lines of inquiry, including analysis of the paleoclimate record, my colleagues and I have concluded that dangerous disruption of current

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[16] UNFCCC, Adoption of the Paris Agreement, Dec. 12, 2015, the full document of which is available at https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.
[17] UNFCCC, Synthesis report on the aggregate effect of the intended nationally determined contributions, Oct. 30, 2015, the full document of which is available at http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf.

climate system to which humanity is adapted likely will commence shy of the politically-driven 2˚C warming target.[18]

80. Moreover, the Parties to the Paris Agreement did not agree to any binding commitments, only announced intentions and precatory exhortations to do more. These intentions and exhortations do not amount to binding, enforceable, emissions reduction commitments. As a result, the Paris Agreement – even if it encourages additional nationally-determined emissions reduction pledges – cannot provide genuine assurance that even the inadequate 2˚C target will be attained and not blown.

81. Accordingly, the substantive utility of the Paris Agreement must reside in the unanimous acknowledgment by the Parties, including by the United States and other major emitters, that their emissions reduction programs and pledges to date fall short of what is minimally required to preserve the fundamental features of a viable planet. Similarly, analysis of the United States' carbon reduction programs and pledges coincident with the Paris Agreement establish that our national effort and pledges to date are inadequate from any reasonable scientific perspective. Indeed, even assuming that the U.S. pledge is converted to a binding program, our country's efforts will fall short of a fair contribution even to halting global warming at 2°C, a target that is itself so lacking in ambition that, even if secured, would be unlikely in the long run to stave off catastrophic change.[19]

[18] *See*, for example, Exhibit 3 at pdf 32, concluding that "the 2°C global warming 'guardrail,' affirmed in the Copenhagen Accord (2009), does not provide safety, as such warming would likely yield sea level rise of several meters along with numerous other disruptive consequences for human society and ecosystems."

[19] To be specific, based on my review of the paleoclimate record, among other factors, I am forced to conclude that, if sea level rise adds to migration pressures from regional climate change, the world could become nearly ungovernable even with global warming of "only" 2°C. On that point s*ee*, for example, our recent comprehensive assessment concluding that "[f]ossil fuel emissions of 1000 GtC, sometimes associated with a 2°C global warming target, would be expected to cause large climate change with disastrous consequences." Hansen, et al, Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature. PLoS ONE (Dec. 3, 2013), Exhibit 2 at 13.

VI. THE FUNDAMENTAL RIGHTS OF CHILDREN AND FUTURE GENERATIONS TO A HABITABLE PLANET

82. With all of the above having now been said, and serving as background, I can return, finally, and briefly, to consider the nature of the violations of the fundamental and inalienable rights of children and future generations that are properly attributable to the actions of the Washington State government, including its Department of Ecology, in particular, Ecology's deliberate disregard for science in setting an initial target of less than 1 percent annual reductions in Washington's total emissions, to commence in 2018, and rising only an additional percentage point over the ensuring 17 years.[20] This comes no where close to necessary minimum action needed to timely reduce atmospheric CO_2 to a safe level which, as discussed above, requires at least 8.5 percent annual emissions reductions, commenced in 2018, coupled with reforestation. *See supra* §70.

83. What must be done to stabilize the climate system so as to preserve a viable future for our children, their progeny, and generations to come? That is a question that I would have presumed would occupy the concern of the Department of Ecology, given my understanding of the agency's legal obligations.

84. Instead, Ecology's proposed Clean Air Rule sets exceedingly weak reduction targets that, if emulated by other states and nations, would ensure a further increase in the atmospheric

[20] According to Ecology, the proposed rule initially covers only two-thirds of the state's emissions. *See* Department of Ecology, SEPA Environmental Checklist - Clean Air Rule at 5, available at http://www.ecy.wa.gov/programs/air/rules/docs/173442sepacheck-2.pdf. Because the proposed rule does not cover all of the state's emitters, I multiplied the portion of the state's emissions covered by the proposed rule (2/3) by the annual proposed reduction for 2018 -- based on Ecology's projected permanent emissions reductions (1.38 percent). The total annual proposed reduction for 2018, then, is only 0.92 percent. *See* Department of Ecology,*Preliminary Cost-Benefit and Least-Burdensom Alternative Analysis: Chapter 173-442 WAC Clean Air Rule, Chapter 173-441 WAC Reporting of Emissions of Greenhouse Gases*, at 18 (June 2016), available at https://fortress.wa.gov/ecy/publications/documents/1602008.pdf. Moreover, over the ensuing 17 years the annual rate of emissions reduction would climb by less than one additional percentage point, still wholly insufficient for Washington to do even its minimum part to achieve global climate stability. *See id*.

concentration of CO_2, and thus a further increase Earth's energy imbalance – *thereby driving our planet towards and potentially beyond irretrievable climate system tipping points*.

85. By enabling continued emissions, such exceedingly weak government action will serve only to lock-in Earth's energy imbalance. It thus jeopardizes the signal features of the relatively benign and favorable climate system that, over the last 10,000 years, enabled civilization to develop and nature to thrive, as I have discussed. These features included relatively stable coastlines, moderate weather, fertile soils, and dependable hydrological systems – the natural capital on which the lives of young people depend no less than did the lives of their parents and *their* forebears. The resulting diminution of young people's life prospects – their compromised ability to earn a living, to meet their basic human needs, to safely raise families, to practice their religious and spiritual beliefs, and otherwise to lead dignified lives – is a predictable if not intended result.

86. In addition, where such government action exacerbates or locks-in Earth's energy imbalance, that, in turn, predictably will lead to the climate change-driven inundation, burning, or other destruction of the value of property in which young people hold interests. These will include the homes, farms and other valuable property that their parents or grandparents own and that young people will inherit.

87. Government action that allows continued high levels of CO_2, in consequence of their long-term impacts on Earth's climate system and the thermal inertia of the ocean, will disproportionately impose harsh burdens on youth and future generations. If fossil fuel emissions are not systematically and rapidly abated, as I have discussed above – including in the materials that I have incorporated by reference – then youth and future generations will confront what reasonably only can be described as, at best, an inhospitable future. That future may be marked

by rising seas, coastal city functionality loss, mass migrations, resource wars, food shortages, heat waves, mega-storms, soil depletion and desiccation, freshwater shortage, public health system collapse, and the extinction of increasing numbers of species. That is to mention only the start of it. At this late stage it is important not to sugarcoat the fundamental assault on their right to equal protection of the law: While prior generations and, to a certain extent, some in our present generation have benefitted and, even, been enriched by the exploitation of fossil fuels, our children and their progeny will not similarly benefit. Indeed, the impact on youth and future generations will be nearly completely to the contrary, as I have discussed.

88. Closely-related to the above, the Washington government and Department of Ecology's continued permitting and promotion of the fossil fuel enterprise now impairs and increasingly will compromise the fundamental natural resources on which youth and future generations will depend. Again, these are the fundamental resources on which the prior and present generations have relied, and on which youth now and in the future must rely. They include the air, freshwater, the oceans and stable shores, the soil and its agronomic capacity, the forests and its wildlife, biodiversity on earth, and the planet's climate system in a form conducive to civilization, humanity and nature as we know it.

89. Furthermore, it is clear to me that young people's right to a government that retains any significant capacity to address the climate crisis adequately is violated by prior and present government actions that exacerbate or lock-in our planet's energy imbalance. In time and, as I have argued, likely within the century, such action will irretrievably damage our planet's favorable climate system. Once begun, for example, collapsing and disintegrating ice sheets will not readily be reformulated – certainly not within a timeframe relevant to present and foreseeable generations. The loss of species too is irretrievable. Many are adapted to specific climate zones,

so those species adapted to polar and alpine regions will have no place to run. Present and pending actions by our government now must be viewed in the context of a climate crisis that our government to date has done so much to bring about. Action is required to preserve and restore the climate system such as we have known it in order for the planet as we have known it to be able to continue adequately to support the lives and prospects of young people and future generations. But that cannot be done effectively by future governments if ours continues to exacerbate the planet's energy imbalance and press our planet towards irretrievable tipping points from which there can be no practical opportunity to return.

90. To further explain this last point, I will note that earlier in this declaration I discussed our nation's outsized role in creating, through its CO_2 emissions, our present emergency with respect to the planet's climate system. *See supra*, text surrounding Chart 4 and Chart 6. It is, accordingly, worthwhile here – in the context of considering responsibility to resolve the present crisis and preserve a habitable climate system – to consider further these top two emitters' role.

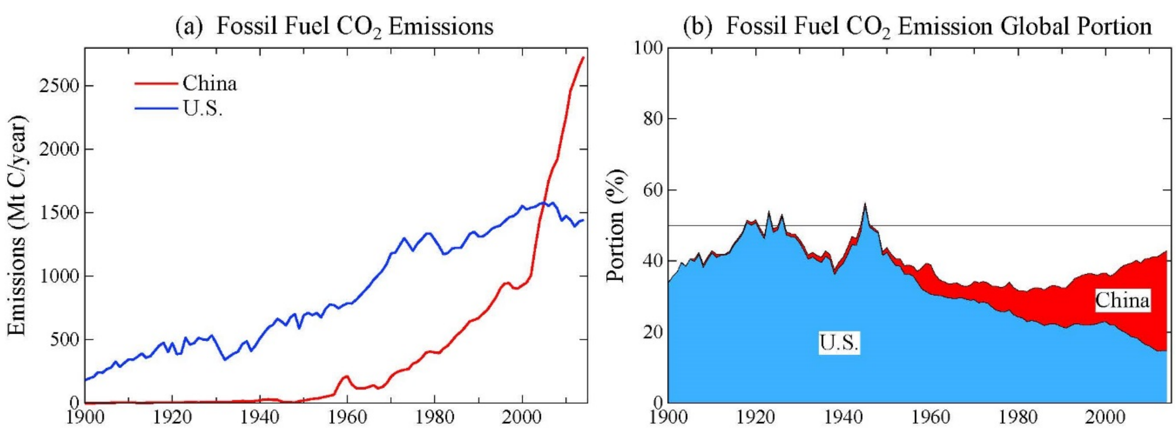

Chart 11: **Top Two Annual Emitters And Their Cumulative Emissions**
(a) Fossil fuel CO_2 Emissions, 1990 Through 2014, (B) Cumulative Shares: U.S. And China
Source: Climate Science, Awareness and Solutions, based on data from ORNL through 2011, updated with BP data through 2014.

91. China's annual CO_2 emissions caught those of the United States in 2005 and then rapidly surpassed U.S. emissions. *See* Chart 11 (a) (left side). However, any sovereign state or nation's contribution to climate change is proportional to its cumulative emissions over time.[21] China's responsibility for global climate change remains a fraction of that of the U.S., despite China's much larger population. *See* Chart 11 (b) (right side). Specifically, China's share of global fossil fuel CO_2 emissions through 2014 is 11.6 percent while the United States share is 25.5 percent.

92. Accordingly, in the light of our nation's preponderant role and the acknowledged "primary responsibility" of States and local governments to prevent and control air pollution at its source, Federal Clean Air Act, 42 U.S.C. §7401(a)(3), the State of Washington retains a special responsibility for helping to solve the global emissions problem. The remaining carbon "budget" – the amount of emissions that can be tolerated while still allowing the possibility of stabilizing climate – is very small. As we have noted, climate stability requires that global emissions decline by at least 8% per year. In effect, the United States burned not only its fair share of the total (cumulative) carbon budget, it also burned much of China and India's fair shares.

93. It is instructive to examine the emissions of China and India, which are shown in Chart 12. China is the #1 global emitter of CO_2 and India is #3, with the United States being #2. Together the three nations emit about half of global emissions, i.e., the same as the other 190 nations of the world combined. Two conclusions leap out from Chart 12. First, emissions in those nations are accelerating rapidly. Second, most of their emissions are from coal burning. (Note that the scale of the vertical axis is different for China and India. India is in an earlier stage of economic development and its emissions are as yet much smaller than China's.)

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[21] Hansen, J., *et al*., Dangerous human-made interference with climate: A GISS modelE study. *Atmos. Chem. Phys.*, **7**, 2287-2312, doi:10.5194/acp-7-2287-2007.

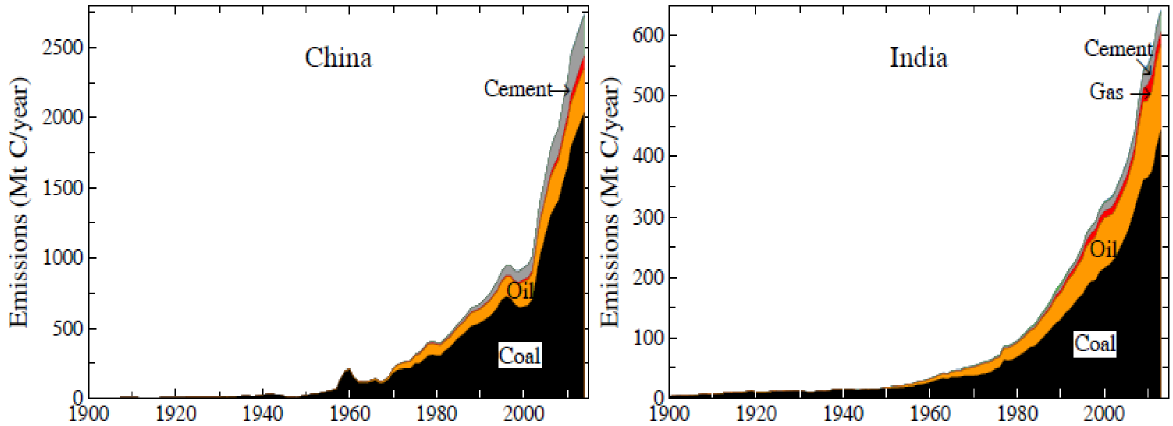

Chart 12: CO_2 Emissions From China (Left Side) And India (Right Side)
Graphic from Climate Science, Awareness and Solutions, utilizing data from the Carbon Dioxide Information Analysis Center and the BP Statistical Review of World Energy (2014).

94. The rapid growth of coal emissions is both a threat to global climate and a source of hope. If coal can be replaced with carbon-free energy, a huge reduction of global emissions becomes possible. In view of the responsibility of the United States for the excess CO_2 in the air today, as well as the fact that U.S. citizens will suffer the consequences of global emissions, it is incumbent upon the U.S. to vigorously assist China with the technology required to replace coal burning. And yet, U.S. action to date have been mostly rhetorical.[22] Governments, both state and federal, need to marshal every available tool, talent, and resource to address and resolve the present crisis with honesty and without further delay.

95. Young people have multiple rights that are guaranteed by our Constitution, including equal protection of the law, equal rights to enjoy life, liberty, property, and the pursuit of happiness – rights that should not be denied without due process. It is the duty of all branches of

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22 EPA's much-vaunted "Clean Power Plan," for example, actually allows U.S. coal-fired power plants to continue to operate for decades, and that Agency itself anticipates that, under the rule, power plant emission reductions will proceed at a slower pace than occurred in the ten-year period *prior* to the rule's enactment.

government to protect those rights. Specifically, it is a duty of sovereign governments and their agencies including, here, Ecology, to lead and propose and pursue policies that achieve the required ends, as opposed to ineffectual actions that are demonstrably far short of what is needed.

96. The essential step, in my view and that of other experts, including economists,[23] is an accord establishing a growing price on CO_2 emissions, which would lead over time to their phase-out. Agreement upon such a domestic fee by major emitters, most notably the United States and China, with a border duty on products from nations that do not have an equivalent domestic carbon fee, would be expected to lead to widespread global movement toward carbon-free energies.

VII. THE URGENT NEED FOR A SCIENCE-BASED CLEAN AIR RULE FROM ECOLOGY

97. I could go on, however, I will end here with a summary statement, in the light of the foregoing material that I have outlined and referenced, and with the offer to further explain my views and reasoning if requested.

98. Simply put: Our state and federal governments' persistent permitting and underwriting of fossil fuel projects serves now to further disrupt the favorable climate system that to date enabled human civilization to develop. In order to preserve a viable climate system, our use of fossil fuels must be phased out as rapidly as is feasible. Only government can ensure this will be done. Instead, sovereign governments seek approval for permitting of fossil fuel infrastructure that would slam shut the narrowing window of opportunity to stabilize climate and ensure a hospitable

[23] These include three co-authors of our 2013 PLOS One study. *See* Exhibit 2. The federal government also has understood the central importance of a rising carbon price, and for at least 25 years. *See*, e.g., Congressional Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases* (1991) at 15 ("a particularly effective way of targeting the heaviest economic sanctions against the worst emitters of CO_2."). As colleagues and I noted in 2013, Exhibit 2 at 19, "[a] rising carbon fee is the *sine qua non* for fossil fuel phase out."

climate and planet for young people and future generations. These projects only allow government trustees to shirk their duty. Governments' permitting of additional, new, or renewed fossil fuel projects is entirely antithetical to its fundamental responsibility to our children and their posterity. Their fundamental rights now hang in the balance.

99. A rapid transition off fossil fuels would have numerous near-term and long-term social benefits, including improved human health and outstanding potential for job creation. There are, accordingly, reasons beyond the mere avoidance of catastrophe for Washington state to institute the necessary changes, such as my colleagues and I have repeatedly urged.[24] But, based on recent history, mere exhortation to voluntary action, whether directed to governments, as discussed above, or to fossil fuel corporations, is unlikely to be effective in time to secure the fundamental interests of young people and future generations.

100. What can be stated with reasonable scientific certainty is that a rapid phase out of fossil fuel emissions by the state, accompanied by widespread improvements in land use aimed to naturally draw down a portion of the excess atmospheric carbon into the terrestrial system, is fully within our technological reach. In Exhibit 2, my colleagues and I laid out scientifically defensible global temperature and atmospheric CO_2 concentration targets and suggested a glide path to achieve these targets.

101. It is urgent that Ecology promulgate a Clean Air Rule based on the currently existing science. Failure to do so serves only to ruin young people's future and violate their fundamental and inalienable rights.

102. Immediate, effective action to restore Earth's energy balance in time to avert wider disintegration of the major ice sheets would achieve multiple benefits, virtually at the same time. These benefits include slowing and eventually stopping sea level rise, averting further

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[24] *See*, for example, Exhibit 2 (Assessing Dangerous Climate Change)

acidification of the oceans and consequential disruption of the marine food chain, slowing and in time stemming the loss of terrestrial species, preserving a viable agricultural system, stemming the growth in wildfires, securing essential water resources – the list goes on.[25]

103. What must be recognized is that atmospheric CO_2 functions now as the control knob for the planet's climate system. Within the remaining period prior to the full manifestation of slow feedbacks and the crossing of climate tipping points of no return, it remains within the power of the state to help dial it back so as to secure a viable future for our children and their progeny. At this late stage all sovereign governments must do their part to turn this thing around.

VIII. RESPONSE TO THE WASHINGTON DEPARTMENT OF ECOLOGY'S INITIAL DENIAL FOR PETITION MAKING AND ASSERTION OF 2°C RATHER THAN 1°C LIMIT ON TEMPERATURE INCREASE

104. Here I wish to examine several points the Washington Department of Ecology employed: (1) to justify its decision, at the time, to offer no recommendation for further emissions reductions, notwithstanding the overriding mandate that the state "do its part to realize climate stabilization levels," RCW 70.235.020(1)(a)(iii), and (2) to support its decision denying in part Youth Petitioners' Petition for Rulemaking for a second time.[26]

105. These justifications have to do with the Agency's assertion that there exists an "international consensus" that global surface temperature "must be kept from rising more than 2°C above the preindustrial average," Ecology Brief at 6, and that the Agency may blithely

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[25] Such action also should avert the feared shutdown of the Atlantic Meridional Overturning Circulation. *See* James Hansen and Makiko Sato, Predictions Implicit in "Ice Melt" Paper and Global Implications, Sept. 21, 2015, available at http://csas.ei.columbia.edu/2015/09/21/predictions-implicit-in-ice-melt-paper-and-global-implications/.

[26] See Brief of Department of Ecology in *Foster v. Ecology*, No. 14-2-25295-1 SEA (Wash. Sup. Ct. Aug. 7, 2015) [hereinafter "Ecology Brief"].

disregard a prescription for emissions reductions that is based on rigorous science because it references work that is not a "global or national assessment of climate change science," Ecology Brief at 7, or because it is "based on work that [Dr. Pushker Kharecha] and his colleague Dr. James Hansen published in [only] one article." *Id*.

106. With all due respect, Ecology's arguments are specious.

107. To take Ecology's last assertions first, the fundamental requirement for rapid phase out of fossil fuel emissions derives not only from the *Dangerous Climate Change* study, of which I was the lead author,[27] but from much other work as well concerning climate sensitivity to various forcings, ocean mixing, impacts on natural and human systems, earth's energy imbalance, and consequences of climate change.

108. For example, in a 2008 study, *Target Atmospheric CO_2: Where Should Humanity Aim?* nine co-authors and I observed that "[p]aleoclimate evidence and ongoing global changes imply that today's CO_2, about 385 ppm, is already too high to maintain the climate to which humanity, wildlife, and the rest of the biosphere are adapted."[28] We suggested "an initial objective of reducing atmospheric CO_2 to 350 ppm" through a practical strategy, including "a rising global price on CO_2 emissions and phase-out of coal use except for cases where the CO_2 is captured and sequestered."[29]

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[27] I had 17 co-authors and not just one, as the Agency's brief implies. Dr. Kharecha was one of those co-authors.

[28] Hansen J, Sato M, Kharecha P, Beerling D, Berner R, et al. (2008) *TargetAtmospheric CO2: Where Should Humanity Aim?* The Open AtmosphericScience Journal 2: 217–231, available at http://benthamopen.com/ABSTRACT/TOASCJ-2-217.

[29] I have published scores of other papers that explore the essential features of earth's climate system and detail the need to phase out fossil fuel emissions rapidly so as to preserve those essential features that enabled human civilization to develop. *See* Exhibit 1 (my CV).

109. Regrettably, in the intervening 8 precious years since Target Atmospheric *CO_2* was published, governments have dithered – except, in the main, to engage in rancorous debate producing lax and highly-perforated carbon caps, among other small steps – while the concentration of atmospheric CO_2 has shot to, and is now going beyond, 400ppm.[30]

110. As for Ecology's objection that our studies are not global or national assessments of climate change science, its assertion is only trivially true since my co-authors and I have not set out to reproduce the work of the Intergovernmental Panel on Climate Change.[31]

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[30] The trends may be usefully explored at the public site of the Earth System Research Laboratory, available at http://www.esrl.noaa.gov/gmd/ccgg/trends/.

[31] Indeed, our work is frequently cited in such assessments. For example, in its chapter evaluating "Long-term Climate Change: Projections, Commitments and Irreversibility," the IPCC, in its most recent assessment, cited our work in 20 places. Our cited studies included:

- Hansen, J., M. Sato, P. Kharecha, and K. von Schuckmann, 2011: Earth's energy imbalance and implications. Atmos. Chem. Phys., 11, 13421–13449.
- Hansen, J., et al., 2008: Target atmospheric CO2: Where should humanity aim? Open Atmos. Sci. J., 2, 217–231.
- Hansen, J., M. Sato, P. Kharecha, G. Russell, D. Lea, and M. Siddall, 2007: Climate change and trace gases. Philos. Trans. R. Soc. A, 365, 1925–1954.
- Hansen, J., et al., 2005: Earth's energy imbalance: Confirmation and implications. Science, 308, 1431–1435.
- Hansen, J., et al., 2005: Efficacy of climate forcings. J. Geophys. Res., 110, D18104.
- Hansen, J., et al., 1988: Global climate changes as forecast by Goddard Institute for Space Studies 3-dimensional model. J. Geophys. Res. Atmos., 93, 9341–9364.
- Hansen, J., G. Russell, A. Lacis, I. Fung, D. Rind, and P. Stone, 1985: Climate response times—Dependence on climate sensitivity and ocean mixing. Science, 229, 857–859.
- Hansen, J., et al., 1984: Climate sensitivity: Analysis of feedback mechanisms. In:
- Climate Processes and Climate Sensitivity [J. Hansen and T. Takahashi (eds.)]. American Geophysical Union, Washington, DC, pp. 130–163.

See Collins, M., R. Knutti et al., *Long-term Climate Change: Projections, Commitments and Irreversibility*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA).

111. The IPCC itself has neither established nor endorsed a target of 2 °C warming over the preindustrial period as a limit below which the climate system will be stable, notwithstanding Ecology's impressively convoluted argument to the contrary. Ecology Brief at 5-6. It is true that the UNFCCC, a political body, has acknowledged "that the rise in average global surface temperature must be kept to less than 2°C." Ecology Brief at 5-6. It is also true that such "assessment" is "consistent with global or national assessments of climate change science." Ecology Brief at 5-6. But again, that is true only in a trivial sense. The relevant science also would be consistent with a hypothetical UNFCCC assessment that the rise in global temperature should be kept to less than 3°C (or, 4, 5, or 10°C). The important question, of course, is "how much less?" That question is the subject of endless debate within the UNFCCC,[32] where delegates jockey over proposed national carbon reduction commitments aimed, alternately, to protect people or major carbon polluters.

112. More importantly, the question also is not answered by the IPCC, that body of scientists that has done so much to bring together climate-relevant information on a six-year basis.[33] In places the IPCC has been clear about this point, noting, for example, that: "each major IPCC

Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter12_FINAL.pdf.

[32] That said, at long last a consensus may be emerging, "although it remained for the parties to articulate." According to a Coordinating Lead Author of the IPCC's Fifth Assessment Report, at a recent "structured expert dialogue" between parties to the UNFCC convention and selected IPCC authors, the 2°C "danger level" seemed "utterly inadequate given the already observed impacts on ecosystems, food, livelihoods, and sustainable development, and the progressively higher risks and lower adaptation potential with rising temperatures, combined with disproportionate vulnerability. Petra Tschakert, *1.5 °C or 2 °C: a conduit's view from the science-policy interface at COP20 in Lima, Peru*, Climate Change Responses (2015) at p. 8 of 11. Available at: http://www.climatechangeresponses.com/content/2/1/3.

[33] The IPCC lays out its multi-year process leading to the publication of each assessment here: http://www.climatechange2013.org/ipcc-process/.

assessment has examined the impacts of [a] multiplicity of temperature changes but has left [it to the] political processes to make decisions on which thresholds may be appropriate."[34]

113. Moreover, the most recent IPCC synthesis of climate science strongly confirms that additional warming of 1^oC (we are now at, approximately, 1^oC above the preindustrial average) jeopardizes unique and threatened systems, including ecosystems and cultures, with certain natural systems and species of limited adaptive capacity considered at "very high risk."[35] The IPCC warns, as well, of risks of extreme events – including heat waves, extreme precipitation, and coastal flooding, and "irreversible regime shifts" with additional warming.[36] *See* Chart 13.

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[34] IPCC, 2014: Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report at 125. Available at http://report.mitigation2014.org/report/ipcc_wg3_ar5_chapter1.pdf.

[35] IPCC 2014: Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press) at 13-14. Available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf.

[36] *Id*. The IPCC also warns that risks are and will be "unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development." *Id*. The IPCC also sees "moderate risk" of global aggregate impacts to our planet's biodiversity and the overall economy with additional warming of 1-2°C, with "extensive biodiversity loss with associated loss of ecosystem goods and services" and accelerated economic damages for additional warming around 3 °C or above. *Id*.

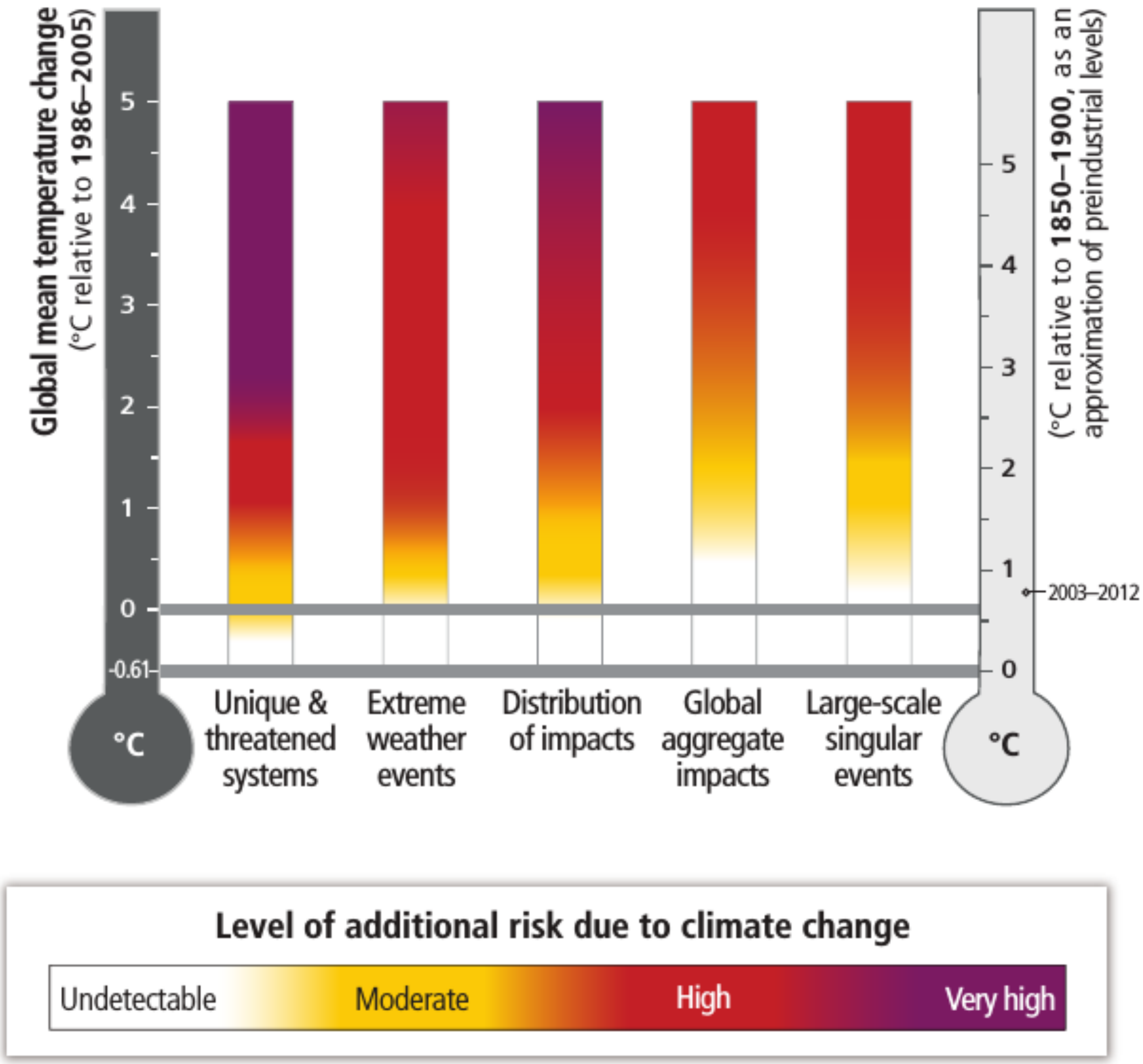

Chart 13 Burning Embers. Illustration of climate risks associated with the IPCC's principally identified reasons for concern. 5th Assessment Report Summary for Policymakers at 13, available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf.

114. Accordingly, while the IPCC has not expressly stated what level of warming is too dangerous, and it likely never will, the answer is plain enough – even based simply on IPCC syntheses – that 2°C warming will be very dangerous.[37] In light of our recent work, I think it is

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[37] For example, Professor Mann of Pennsylvania State University, argued in 2009 that, given the risks to threatened systems, risks associated with extreme weather, and the "distribution of impacts [that may] weigh heavily toward being adverse across diverse regions at ~1 °C

clear that such warming, if maintained (or exceeded) even for decades, will produce calamitous effects to human and natural systems alike.

115. I conclude that the state of climate science, even though the year 2014, provided the State of Washington with far more than ample reason to abandon the fundamentally arbitrary 2°C mark as any guide to the formation of an adequate state program with respect to CO_2 emissions.

116. Here I must add to the IPCC litany an additional reason for concern about Ecology's presumption that the 2°C warming mark is, plausibly, acceptable. That reason is the very real potential for nonlinear disintegration of our planet's major ice sheets, and the multi-meter sea level rise within this century that may well result. *See Ice Melt*, Exhibit 3.

117. Ecology appears to be reprising the path that led to the Kyoto and European Trading Scheme debacles, or worse: "a regulatory cap," that "will not charge emitters for carbon pollution," but will allow for unrestrained trading among emitters, and that aims to achieve "emission limits" set in 2008, which limits Ecology itself deems inadequate. *See* Ecology Report of Dec. 2014[38], at vi ("Washington State's existing statutory limits should be adjusted to better reflect the current science. The limits need to be more aggressive in order for Washington to do its part to address climate risks and to align our limits with other jurisdictions that are taking responsibility to address these risks.").

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additional global mean warming (defined relative to a 1990 baseline), it would seem difficult for the risk averse among us to accept anything much above that as the standard" for dangerous anthropogenic interference with the climate system. Michael E. Mann, *Defining dangerous anthropogenic interference*, Proceedings of the National Academic of Sciences (March 17, 2009) at 4065. Available at http://www.pnas.org/content/106/11/4065.full.pdf.

[38] Dep't of Ecology, *Washington Greenhouse Gas Emission Reduction Limits: Report Prepared Under RCW 70.235.040* (Dec. 2014).

118. What is required, instead, is a binding commitment to maximize emissions reductions so as effectively to phase out fossil fuel utilization (unless associated emissions are fully and effectively sequestered) well before the end of the century. Neither the achievement of the 2008-set limits, nor some less specified, albeit "substantive," reduction, as Ecology promises in its briefing, Ecology Brief at 9, will suffice to protect the rights of youth and future generations.[39] The centerpiece of an effective system – its *sin qua non* – must be a carbon fee that rises to the point that major emitters bear the full social cost they impose on society, including those imposed upon our children and future generations.

[39] The error is akin to a ship's captain tossing out a life preserver that can support only one or a few jettisoned passengers. The fear and ire of the passengers likely will not be mollified by the captain's assertion that he has, after all, lent out a substantive floatation device.

I am prepared, as necessary and schedule permitting, to further explain or elaborate on any of the points I have made in this declaration for Ecology.

I swear, under penalty of perjury, pursuant to the laws of the State of Washington, that the foregoing is true and correct.

Executed this _21_ day of July, 2016 in New York City, New York.

James E Hansen

DR. JAMES E. HANSEN

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Review

Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature

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Abstract: We assess climate impacts of global warming using ongoing observations and paleoclimate data. We use Earth's measured energy imbalance, paleoclimate data, and simple representations of the global carbon cycle and temperature to define emission reductions needed to stabilize climate and avoid potentially disastrous impacts on today's young people, future generations, and nature. A cumulative industrial-era limit of ~500 GtC fossil fuel emissions and 100 GtC storage in the biosphere and soil would keep climate close to the Holocene range to which humanity and other species are adapted. Cumulative emissions of ~1000 GtC, sometimes associated with 2°C global warming, would spur "slow" feedbacks and eventual warming of 3–4°C with disastrous consequences. Rapid emissions reduction is required to restore Earth's energy balance and avoid ocean heat uptake that would practically guarantee irreversible effects. Continuation of high fossil fuel emissions, given current knowledge of the consequences, would be an act of extraordinary witting intergenerational injustice. Responsible policymaking requires a rising price on carbon emissions that would preclude emissions from most remaining coal and unconventional fossil fuels and phase down emissions from conventional fossil fuels.

Introduction

Humans are now the main cause of changes of Earth's atmospheric composition and thus the drive for future climate change [1]. The principal climate forcing, defined as an imposed change of planetary energy balance [1–2], is increasing carbon dioxide (CO_2) from fossil fuel emissions, much of which will remain in the atmosphere for millennia [1,3]. The climate response to this forcing and society's response to climate change are complicated by the system's inertia, mainly due to the ocean and the ice sheets on Greenland and Antarctica together with the long residence time of fossil fuel carbon in the climate system. The inertia causes climate to appear to respond slowly to this human-made forcing, but further long-lasting responses can be locked in.

More than 170 nations have agreed on the need to limit fossil fuel emissions to avoid dangerous human-made climate change, as formalized in the 1992 Framework Convention on Climate Change [6]. However, the stark reality is that global emissions have accelerated (Fig. 1) and new efforts are underway to massively expand fossil fuel extraction [7–9] by drilling to increasing ocean depths and into the Arctic, squeezing oil from tar sands and tar shale, hydro-fracking to expand extraction of natural gas, developing exploitation of methane hydrates, and mining of coal via mountaintop removal and mechanized long-wall mining. The growth rate of fossil fuel emissions increased from 1.5%/year during 1980–2000 to 3%/year in 2000–2012, mainly because of increased coal use [4–5].

The Framework Convention [6] does not define a dangerous level for global warming or an emissions limit for fossil fuels. The

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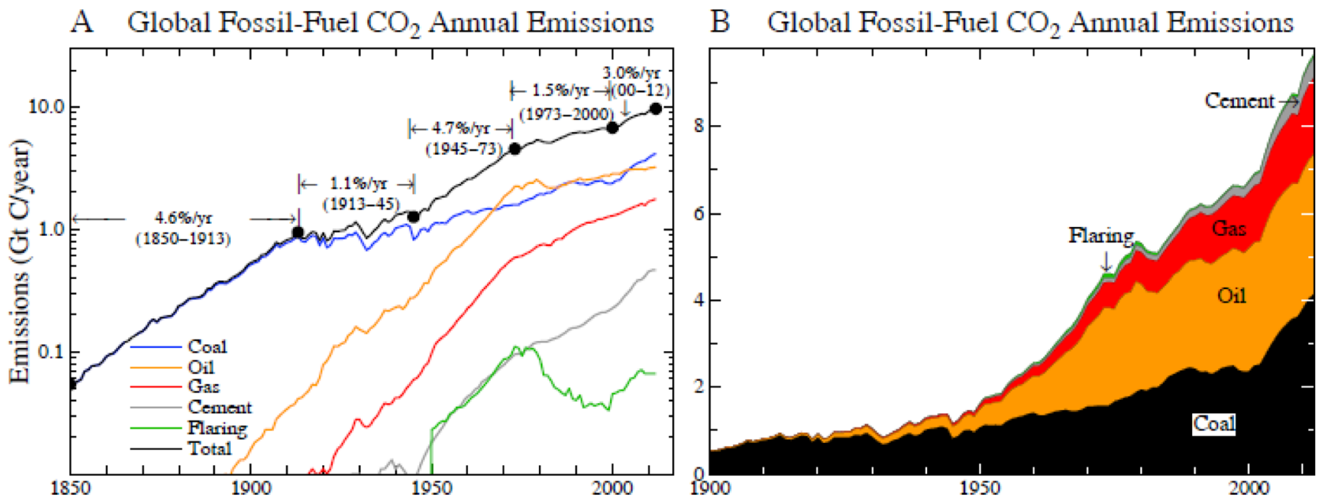

Figure 1. CO_2 annual emissions from fossil fuel use and cement manufacture, based on data of British Petroleum [4] concatenated with data of Boden et al. [5]. (A) is log scale and (B) is linear.
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European Union in 1996 proposed to limit global warming to 2°C relative to pre-industrial times [10], based partly on evidence that many ecosystems are at risk with larger climate change. The 2°C target was reaffirmed in the 2009 "Copenhagen Accord" emerging from the 15th Conference of the Parties of the Framework Convention [11], with specific language "We agree that deep cuts in global emissions are required according to science, as documented in the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius…".

A global warming target is converted to a fossil fuel emissions target with the help of global climate-carbon-cycle models, which reveal that eventual warming depends on cumulative carbon emissions, not on the temporal history of emissions [12]. The emission limit depends on climate sensitivity, but central estimates [12–13], including those in the upcoming Fifth Assessment of the Intergovernmental Panel on Climate Change [14], are that a 2°C global warming limit implies a cumulative carbon emissions limit of the order of 1000 GtC. In comparing carbon emissions, note that some authors emphasize the sum of fossil fuel and deforestation carbon. We bookkeep fossil fuel and deforestation carbon separately, because the larger fossil fuel term is known more accurately and this carbon stays in the climate system for hundreds of thousands of years. Thus fossil fuel carbon is the crucial human input that must be limited. Deforestation carbon is more uncertain and potentially can be offset on the century time scale by storage in the biosphere, including the soil, via reforestation and improved agricultural and forestry practices.

There are sufficient fossil fuel resources to readily supply 1000 GtC, as fossil fuel emissions to date (370 GtC) are only a small fraction of potential emissions from known reserves and potentially recoverable resources (Fig. 2). Although there are uncertainties in reserves and resources, ongoing fossil fuel subsidies and continuing technological advances ensure that more and more of these fuels will be economically recoverable. As we will show, Earth's paleoclimate record makes it clear that the CO_2 produced by burning all or most of these fossil fuels would lead to a very different planet than the one that humanity knows.

Our evaluation of a fossil fuel emissions limit is not based on climate models but rather on observational evidence of global climate change as a function of global temperature and on the fact that climate stabilization requires long-term planetary energy balance. We use measured global temperature and Earth's measured energy imbalance to determine the atmospheric CO_2 level required to stabilize climate at today's global temperature, which is near the upper end of the global temperature range in the current interglacial period (the Holocene). We then examine climate impacts during the past few decades of global warming and in paleoclimate records including the Eemian period, concluding that there are already clear indications of undesirable impacts at the current level of warming and that 2°C warming would have major deleterious consequences. We use simple representations of the carbon cycle and global temperature, consistent with observations, to simulate transient global temperature and assess carbon emission scenarios that could keep global climate near the Holocene range. Finally, we discuss likely overshooting of target emissions, the potential for carbon extraction from the atmosphere, and implications for energy and economic policies, as well as intergenerational justice.

Global Temperature and Earth's Energy Balance

Global temperature and Earth's energy imbalance provide our most useful measuring sticks for quantifying global climate change and the changes of global climate forcings that would be required to stabilize global climate. Thus we must first quantify knowledge of these quantities.

Temperature

Temperature change in the past century (Fig. 3; update of figures in [16]) includes unforced variability and forced climate change. The long-term global warming trend is predominantly a forced climate change caused by increased human-made atmospheric gases, mainly CO_2 [1]. Increase of "greenhouse" gases such as CO_2 has little effect on incoming sunlight but makes the atmosphere more opaque at infrared wavelengths, causing infrared (heat) radiation to space to emerge from higher, colder levels, which thus reduces infrared radiation to space. The resulting planetary energy imbalance, absorbed solar energy exceeding heat emitted to space, causes Earth to warm. Observations, discussed below, confirm that Earth is now substantially out of energy balance, so the long-term warming will continue.

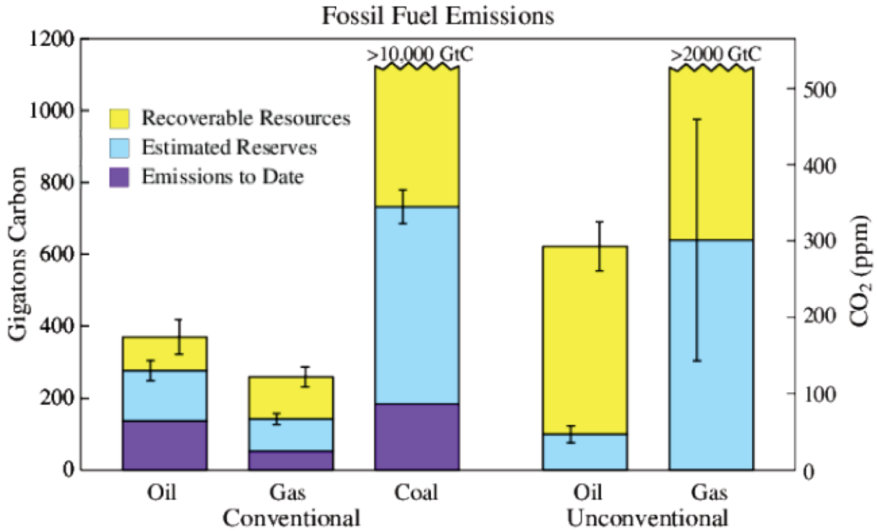

Figure 2. Fossil fuel CO_2 emissions and carbon content (1 ppm atmospheric CO_2 ~ 2.12 GtC). Estimates of reserves (profitable to extract at current prices) and resources (potentially recoverable with advanced technology and/or at higher prices) are the mean of estimates of Energy Information Administration (EIA) [7], German Advisory Council (GAC) [8], and Global Energy Assessment (GEA) [9]. GEA [9] suggests the possibility of >15,000 GtC unconventional gas. Error estimates (vertical lines) are from GEA and probably underestimate the total uncertainty. We convert energy content to carbon content using emission factors of Table 4.2 of [15] for coal, gas and conventional oil, and, also following [15], emission factor of unconventional oil is approximated as being the same as for coal. Total emissions through 2012, including gas flaring and cement manufacture, are 384 GtC; fossil fuel emissions alone are ~370 GtC.
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Global temperature appears to have leveled off since 1998 (Fig. 3a). That plateau is partly an illusion due to the 1998 global temperature spike caused by the El Niño of the century that year. The 11-year (132-month) running mean temperature (Fig. 3b) shows only a moderate decline of the warming rate. The 11-year averaging period minimizes the effect of variability due to the 10–12 year periodicity of solar irradiance as well as irregular El Niño/La Niña warming/cooling in the tropical Pacific Ocean. The current solar cycle has weaker irradiance than the several prior solar cycles, but the decreased irradiance can only partially account for the decreased warming rate [17]. Variability of the El Niño/La Niña cycle, described as a Pacific Decadal Oscillation, largely accounts for the temporary decrease of warming [18], as we discuss further below in conjunction with global temperature simulations.

Assessments of dangerous climate change have focused on estimating a permissible level of global warming. The Intergovernmental Panel on Climate Change [1,19] summarized broad-based assessments with a "burning embers" diagram, which indicated that major problems begin with global warming of 2–3°C. A probabilistic analysis [20], still partly subjective, found a median "dangerous" threshold of 2.8°C, with 95% confidence that the dangerous threshold was 1.5°C or higher. These assessments were relative to global temperature in year 1990, so add 0.6°C to these values to obtain the warming relative to 1880–1920, which is the base period we use in this paper for preindustrial time. 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.

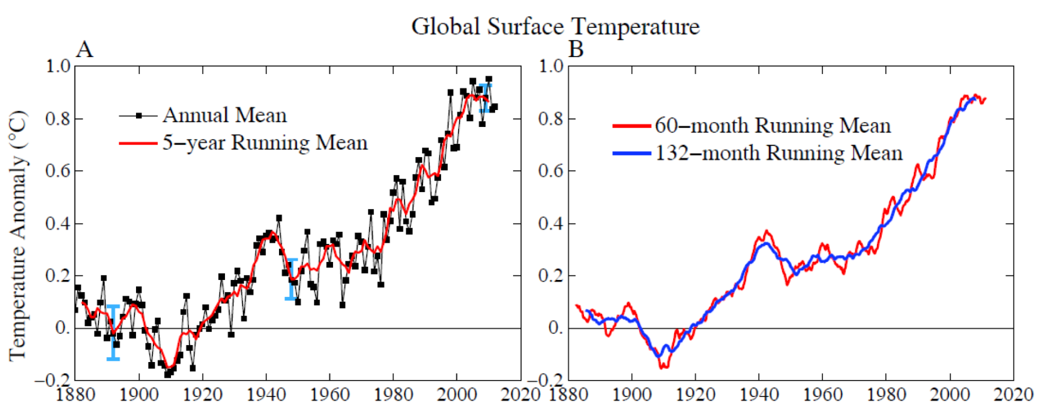

Figure 3. Global surface temperature relative to 1880–1920 mean. B shows the 5 and 11 year means. Figures are updates of [16] using data through August 2013.
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The fallacy of this logic emerged recently as numerous impacts of ongoing global warming emerged and as paleoclimate implications for climate sensitivity became apparent. Arctic sea ice end-of-summer minimum area, although variable from year to year, has plummeted by more than a third in the past few decades, at a faster rate than in most models [21], with the sea ice thickness declining a factor of four faster than simulated in IPCC climate models [22]. 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 [23–25]. Mountain glaciers are receding rapidly all around the world [26–29] with effects on seasonal freshwater availability of major rivers [30–32]. The hot dry subtropical climate belts have expanded as the troposphere has warmed and the stratosphere cooled [33–36], contributing to increases in the area and intensity of drought [37] and wildfires [38]. The abundance of reef-building corals is decreasing at a rate of 0.5–2%/year, at least in part due to ocean warming and possibly ocean acidification caused by rising dissolved CO_2 [39–41]. More than half of all wild species have shown significant changes in where they live and in the timing of major life events [42–44]. Mega-heatwaves, such as those in Europe in 2003, the Moscow area in 2010, Texas and Oklahoma in 2011, Greenland in 2012, and Australia in 2013 have become more widespread with the increase demonstrably linked to global warming [45–47].

These growing climate impacts, many more rapid than anticipated and occurring while global warming is less than 1°C, imply that society should reassess what constitutes a "dangerous level" of global warming. Earth's paleoclimate history provides a valuable tool for that purpose.

Paleoclimate Temperature

Major progress in quantitative understanding of climate change has occurred recently by use of the combination of data from high resolution ice cores covering time scales of order several hundred thousand years [48–49] and ocean cores for time scales of order one hundred million years [50]. Quantitative insights on global temperature sensitivity to external forcings [51–52] and sea level sensitivity to global temperature [52–53] are crucial to our analyses. Paleoclimate data also provide quantitative information about how nominally slow feedback processes amplify climate sensitivity [51–52,54–56], which also is important to our analyses.

Earth's surface temperature prior to instrumental measurements is estimated via proxy data. We will refer to the surface temperature record in Fig. 4 of a recent paper [52]. Global mean temperature during the Eemian interglacial period (120,000 years ago) is constrained to be 2°C warmer than our pre-industrial (1880–1920) level based on several studies of Eemian climate [52]. The concatenation of modern and instrumental records [52] is based on an estimate that global temperature in the first decade of the 21st century (+0.8°C relative to 1880–1920) exceeded the Holocene mean by 0.25 ± 0.25°C. That estimate was based in part on the fact that sea level is now rising 3.2 mm/yr (3.2 m/millennium) [57], an order of magnitude faster than the rate during the prior several thousand years, with rapid change of ice sheet mass balance over the past few decades [23] and Greenland and Antarctica now losing mass at accelerating rates [23–24]. This concatenation, which has global temperature 13.9°C in the base period 1951–1980, has the first decade of the 21st century slightly (~0.1°C) warmer than the early Holocene maximum. A recent reconstruction from proxy temperature data [55] concluded that global temperature declined about 0.7°C between the Holocene maximum and a pre-industrial minimum before recent warming brought temperature back near the Holocene maximum, which is consistent with our analysis.

Climate oscillations evident in Fig. 4 of Hansen et al. [52] were instigated by perturbations of Earth's orbit and spin axis tilt relative to the orbital plane, which alter the geographical and seasonal distribution of sunlight on Earth [58]. These forcings change slowly, with periods between 20,000 and 400,000 years, and thus climate is able to stay in quasi-equilibrium with these forcings. Slow insolation changes initiated the climate oscillations, but 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 atmospheric CO_2 amount. As the planet warms, 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. Together with fast feedbacks processes, via changes of water vapor, clouds, and the vertical temperature profile, these slow amplifying feedbacks were responsible for almost the entire glacial-to-interglacial temperature change [59–62].

The albedo and CO_2 feedbacks amplified weak orbital forcings, the feedbacks necessarily changing slowly over millennia, at the pace of orbital changes. Today, however, CO_2 is under the control of humans as fossil fuel emissions overwhelm natural changes. Atmospheric CO_2 has increased rapidly to a level not seen for at least 3 million years [56,63]. Global warming induced by increasing CO_2 will cause ice to melt and hence sea level to rise as the global volume of ice moves toward the quasi-equilibrium amount that exists for a given global temperature [53]. As ice melts and ice area decreases, the albedo feedback will amplify global warming.

Earth, because of the climate system's inertia, has not yet fully responded to human-made changes of atmospheric composition. The ocean's thermal inertia, which delays some global warming for decades and even centuries, is accounted for in global climate models and its effect is confirmed via measurements of Earth's energy balance (see next section). In addition there are slow climate feedbacks, such as changes of ice sheet size, that occur mainly over centuries and millennia. Slow feedbacks have little effect on the immediate planetary energy balance, instead coming into play in response to temperature change. The slow feedbacks are difficult to model, but paleoclimate data and observations of ongoing changes help provide quantification.

Earth's Energy Imbalance

At a time of climate stability, Earth radiates as much energy to space as it absorbs from sunlight. Today Earth is out of balance because increasing atmospheric gases such as CO_2 reduce Earth's heat radiation to space, thus causing an energy imbalance, as there is less energy going out than coming in. This imbalance causes Earth to warm and move back toward energy balance. The warming and restoration of energy balance take time, however, because of Earth's thermal inertia, which is due mainly to the global ocean.

Earth warmed about 0.8°C in the past century. That warming increased Earth's radiation to space, thus reducing Earth's energy imbalance. The remaining energy imbalance helps us assess how much additional warming is still "in the pipeline". Of course increasing CO_2 is only one of the factors affecting Earth's energy balance, even though it is the largest climate forcing. Other forcings include changes of aerosols, solar irradiance, and Earth's surface albedo.

Determination of the state of Earth's climate therefore requires measuring the energy imbalance. This is a challenge, because the imbalance is expected to be only about 1 W/m^2 or less, so accuracy approaching 0.1 W/m^2 is needed. The most promising

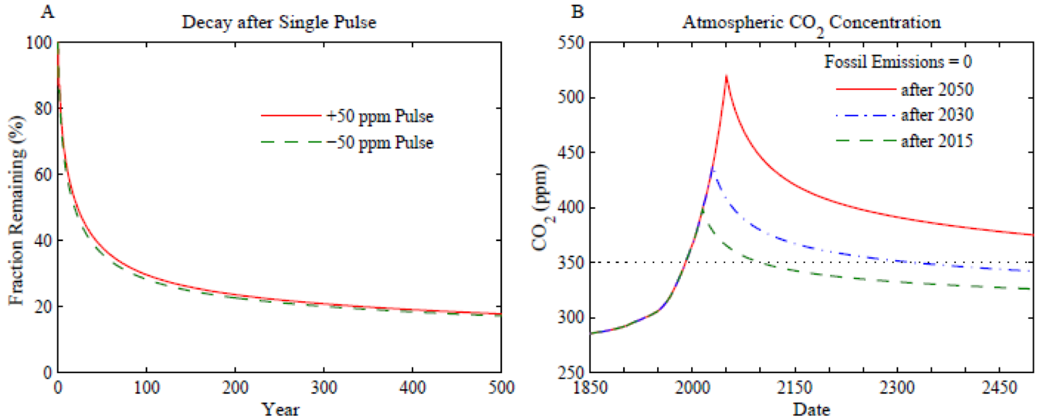

Figure 4. Decay of atmospheric CO_2 perturbations. (A) Instantaneous injection or extraction of CO_2 with initial conditions at equilibrium. (B) Fossil fuel emissions terminate at the end of 2015, 2030, or 2050 and land use emissions terminate after 2015 in all three cases, i.e., thereafter there is no net deforestation.
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approach is to measure the rate of changing heat content of the ocean, atmosphere, land, and ice [64]. Measurement of ocean heat content is the most critical observation, as nearly 90 percent of the energy surplus is stored in the ocean [64–65].

Observed Energy Imbalance

Nations of the world have launched a cooperative program to measure changing ocean heat content, distributing more than 3000 Argo floats around the world ocean, with each float repeatedly diving to a depth of 2 km and back [66]. Ocean coverage by floats reached 90% by 2005 [66], with the gaps mainly in sea ice regions, yielding the potential for an accurate energy balance assessment, provided that several systematic measurement biases exposed in the past decade are minimized [67–69].

Argo data reveal that in 2005–2010 the ocean's upper 2000 m gained heat at a rate equal to 0.41 W/m^2 averaged over Earth's surface [70]. Smaller contributions to planetary energy imbalance are from heat gain by the deeper ocean (+0.10 W/m^2), energy used in net melting of ice (+0.05 W/m^2), and energy taken up by warming continents (+0.02 W/m^2). Data sources for these estimates and uncertainties are provided elsewhere [64]. The resulting net planetary energy imbalance for the six years 2005–2010 is $+0.58\pm0.15$ W/m^2.

The positive energy imbalance in 2005–2010 confirms that the effect of solar variability on climate is much less than the effect of human-made greenhouse gases. If the sun were the dominant forcing, the planet would have a negative energy balance in 2005–2010, when solar irradiance was at its lowest level in the period of accurate data, i.e., since the 1970s [64,71]. Even though much of the greenhouse gas forcing has been expended in causing observed 0.8°C global warming, the residual positive forcing overwhelms the negative solar forcing. The full amplitude of solar cycle forcing is about 0.25 W/m^2 [64,71], but the reduction of solar forcing due to the present weak solar cycle is about half that magnitude as we illustrate below, so the energy imbalance measured during solar minimum (0.58 W/m^2) suggests an average imbalance over the solar cycle of about 0.7 W/m^2.

Earth's measured energy imbalance has been used to infer the climate forcing by aerosols, with two independent analyses yielding a forcing in the past decade of about -1.5 W/m^2 [64,72], including the direct aerosol forcing and indirect effects via induced cloud changes. Given this large (negative) aerosol forcing, precise monitoring of changing aerosols is needed [73]. Public reaction to increasingly bad air quality in developing regions [74] may lead to future aerosol reductions, at least on a regional basis. Increase of Earth's energy imbalance from reduction of particulate air pollution, which is needed for the sake of human health, can be minimized via an emphasis on reducing absorbing black soot [75], but the potential to constrain the net increase of climate forcing by focusing on black soot is limited [76].

Energy Imbalance Implications for CO_2 Target

Earth's energy imbalance is the most vital number characterizing the state of Earth's climate. It informs us about the global temperature change "in the pipeline" without further change of climate forcings and it defines how much greenhouse gases must be reduced to restore Earth's energy balance, which, at least to a good approximation, must be the requirement for stabilizing global climate. The measured energy imbalance accounts for all natural and human-made climate forcings, including changes of atmospheric aerosols and Earth's surface albedo.

If Earth's mean energy imbalance today is +0.5 W/m^2, CO_2 must be reduced from the current level of 395 ppm (global-mean annual-mean in mid-2013) to about 360 ppm to increase Earth's heat radiation to space by 0.5 W/m^2 and restore energy balance. If Earth's energy imbalance is 0.75 W/m^2, CO_2 must be reduced to about 345 ppm to restore energy balance [64,75].

The measured energy imbalance indicates that an initial CO_2 target "$<$350 ppm" would be appropriate, if the aim is to stabilize climate without further global warming. That target is consistent with an earlier analysis [54]. Additional support for that target is provided by our analyses of ongoing climate change and paleoclimate, in later parts of our paper. Specification now of a CO_2 target more precise than $<$350 ppm is difficult and unnecessary, because of uncertain future changes of forcings including other gases, aerosols and surface albedo. More precise assessments will become available during the time that it takes to turn around CO_2 growth and approach the initial 350 ppm target.

Below we find the decreasing emissions scenario that would achieve the 350 ppm target within the present century. Specifically, we want to know the annual percentage rate at which emissions must be reduced to reach this target, and the dependence of this rate upon the date at which reductions are initiated. This approach is complementary to the approach of estimating cumulative emissions allowed to achieve a given limit on global warming [12].

If the only human-made climate forcing were changes of atmospheric CO_2, the appropriate CO_2 target might be close to the pre-industrial CO_2 amount [53]. However, there are other human forcings, including aerosols, the effect of aerosols on clouds, non-CO_2 greenhouse gases, and changes of surface albedo that will not disappear even if fossil fuel burning is phased out. Aerosol forcings are substantially a result of fossil fuel burning [1,76], but the net aerosol forcing is a sensitive function of various aerosol sources [76]. The indirect aerosol effect on clouds is non-linear [1,76] such that it has been suggested that even the modest aerosol amounts added by pre-industrial humans to an otherwise pristine atmosphere may have caused a significant climate forcing [59]. Thus continued precise monitoring of Earth's radiation imbalance is probably the best way to assess and adjust the appropriate CO_2 target.

Ironically, future reductions of particulate air pollution may exacerbate global warming by reducing the cooling effect of reflective aerosols. However, a concerted effort to reduce non-CO_2 forcings by methane, tropospheric ozone, other trace gases, and black soot might counteract the warming from a decline in reflective aerosols [54,75]. Our calculations below of future global temperature assume such compensation, as a first approximation. To the extent that goal is not achieved, adjustments must be made in the CO_2 target or future warming may exceed calculated values.

Climate Impacts

Determination of the dangerous level of global warming inherently is partly subjective, but we must be as quantitative as possible. Early estimates for dangerous global warming based on the "burning embers" approach [1,19–20] have been recognized as probably being too conservative [77]. A target of limiting warming to 2°C has been widely adopted, as discussed above. We suspect, however, that this may be a case of inching toward a better answer. If our suspicion is correct, then that gradual approach is itself very dangerous, because of the climate system's inertia. It will become exceedingly difficult to keep warming below a target smaller than 2°C, if high emissions continue much longer.

We consider several important climate impacts and use evidence from current observations to assess the effect of 0.8°C warming and paleoclimate data for the effect of larger warming, especially the Eemian period, which had global mean temperature about +2°C relative to pre-industrial time. Impacts of special interest are sea level rise and species extermination, because they are practically irreversible, and others important to humankind.

Sea Level

The prior interglacial period, the Eemian, was at most ~2°C warmer than 1880–1920 (Fig. 3). Sea level reached heights several meters above today's level [78–80], probably with instances of sea level change of the order of 1 m/century [81–83]. Geologic shoreline evidence has been interpreted as indicating a rapid sea level rise of a few meters late in the Eemian to a peak about 9 meters above present, suggesting the possibility that a critical stability threshold was crossed that caused polar ice sheet collapse [84–85], although there remains debate within the research community about this specific history and interpretation. The large Eemian sea level excursions imply that substantial ice sheet melting occurred when the world was little warmer than today.

During the early Pliocene, which was only ~3°C warmer than the Holocene, sea level attained heights as much as 15–25 meters higher than today [53,86–89]. Such sea level rise suggests that parts of East Antarctica must be vulnerable to eventual melting with global temperature increase of a few degrees Celsius. Indeed, satellite gravity data and radar altimetry reveal that the Totten Glacier of East Antarctica, which fronts a large ice mass grounded below sea level, is now losing mass [90].

Greenland ice core data suggest that the Greenland ice sheet response to Eemian warmth was limited [91], but the fifth IPCC assessment [14] concludes that Greenland very likely contributed between 1.4 and 4.3 m to the higher sea level of the Eemian. The West Antarctic ice sheet is probably more susceptible to rapid change, because much of it rests on bedrock well below sea level [92–93]. Thus the entire 3–4 meters of global sea level contained in that ice sheet may be vulnerable to rapid disintegration, although arguments for stability of even this marine ice sheet have been made [94]. However, Earth's history reveals sea level changes of as much as a few meters per century, even though the natural climate forcings changed much more slowly than the present human-made forcing.

Expected human-caused sea level rise is controversial in part because predictions focus on sea level at a specific time, 2100. Sea level on a given date is inherently difficult to predict, as it depends on how rapidly non-linear ice sheet disintegration begins. Focus on a single date also encourages people to take the estimated result as an indication of what humanity faces, thus failing to emphasize that the likely rate of sea level rise immediately after 2100 will be much larger than within the 21st century, especially if CO_2 emissions continue to increase.

Recent estimates of sea level rise by 2100 have been of the order of 1 m [95–96], which is higher than earlier assessments [26], but these estimates still in part assume linear relations between warming and sea level rise. It has been argued [97–98] that continued business-as-usual CO_2 emissions are likely to spur a nonlinear response with multi-meter sea level rise this century. Greenland and Antarctica have been losing mass at rapidly increasing rates during the period of accurate satellite data [23]; the data are suggestive of exponential increase, but the records are too short to be conclusive. The area on Greenland with summer melt has increased markedly, with 97% of Greenland experiencing melt in 2012 [99].

The important point is that the uncertainty is not about whether continued rapid CO_2 emissions would cause large sea level rise, submerging global coastlines – it is about how soon the large changes would begin. The carbon from fossil fuel burning will remain in and affect the climate system for many millennia, ensuring that over time sea level rise of many meters will occur – tens of meters if most of the fossil fuels are burned [53]. That order of sea level rise would result in the loss of hundreds of historical coastal cities worldwide with incalculable economic consequences, create hundreds of millions of global warming refugees from highly-populated low-lying areas, and thus likely cause major international conflicts.

Shifting Climate Zones

Theory and climate models indicate that the tropical overturning (Hadley) atmospheric circulation expands poleward with global warming [33]. There is evidence in satellite and radiosonde data and in observational data for poleward expansion of the tropical circulation by as much as a few degrees of latitude since the 1970s [34–35], but natural variability may have contributed to that expansion [36]. Change in the overturning circulation likely contributes to expansion of subtropical conditions and increased aridity in the southern United States [30,100], the Mediterranean region, South America, southern Africa, Madagascar, and southern Australia. Increased aridity and temperature contribute to increased forest fires that burn hotter and are more destructive [38].

Despite large year-to-year variability of temperature, decadal averages reveal isotherms (lines of a given average temperature) moving poleward at a typical rate of the order of 100 km/decade in the past three decades [101], although the range shifts for specific species follow more complex patterns [102]. This rapid shifting of climate zones far exceeds natural rates of change. Movement has been in the same direction (poleward, and upward in elevation) since about 1975. Wild species have responded to climate change, with three-quarters of marine species shifting their ranges poleward as much as 1000 km [44,103] and more than half of terrestrial species shifting ranges poleward as much as 600 km and upward as much as 400 m [104].

Humans may adapt to shifting climate zones better than many species. However, political borders can interfere with human migration, and indigenous ways of life already have been adversely affected [26]. Impacts are apparent in the Arctic, with melting tundra, reduced sea ice, and increased shoreline erosion. Effects of shifting climate zones also may 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.

Human Extermination of Species

Biodiversity is affected by many agents including overharvesting, introduction of exotic species, land use changes, nitrogen fertilization, and direct effects of increased atmospheric CO_2 on plant ecophysiology [43]. However, an overriding role of climate change is exposed by diverse effects of rapid warming on animals, plants, and insects in the past three decades.

A sudden widespread decline of frogs, with extinction of entire mountain-restricted species attributed to global warming [105–106], provided a dramatic awakening. There are multiple causes of the detailed processes involved in global amphibian declines and extinctions [107–108], but global warming is a key contributor and portends a planetary-scale mass extinction in the making unless action is taken to stabilize climate while also fighting biodiversity's other threats [109].

Mountain-restricted and polar-restricted species are particularly vulnerable. As isotherms move up the mountainside and poleward, so does the climate zone in which a given species can survive. If global warming continues unabated, many of these species will be effectively pushed off the planet. There are already reductions in the population and health of Arctic species in the southern parts of the Arctic, Antarctic species in the northern parts of the Antarctic, and alpine species worldwide [43].

A critical factor for survival of some Arctic species is retention of all-year sea ice. Continued growth of fossil fuel emissions will cause loss of all Arctic summer sea ice within several decades. In contrast, the scenario in Fig. 5A, with global warming peaking just over 1°C and then declining slowly, should allow 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 reflect 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 and mountain ranges. As the shift of climate zones [110] becomes comparable to the range of some species, less mobile species can be driven to extinction. Because of extensive species interdependencies, this can lead to mass extinctions.

Rising sea level poses a threat to a large number of uniquely evolved endemic fauna living on islands in marine-dominated ecosystems, with those living on low lying islands being especially vulnerable. Evolutionary history on Bermuda offers numerous examples of the direct and indirect impact of changing sea level on evolutionary processes [111–112], with a number of taxa being extirpated due to habitat changes, greater competition, and island inundation [113]. Similarly, on Aldahabra Island in the Indian Ocean, land tortoises were exterminated during sea level high stands [114]. Vulnerabilities would be magnified by the speed of human-made climate change and the potentially large sea level rise [115].

IPCC [26] reviewed studies relevant to estimating eventual extinctions. They estimate that if global warming exceeds 1.6°C above preindustrial, 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. A comprehensive study of biodiversity indicators over the past decade [116] reveals that, despite some local success in increasing extent of protected areas, overall indicators of pressures on biodiversity including that due to climate change are continuing to increase and indicators of the state of biodiversity are continuing to decline.

Mass extinctions occurred several times in Earth's history [117–118], often in conjunction with rapid climate change. New species evolved over millions of years, but those time scales are almost beyond human comprehension. If we drive many species to extinction we will leave a more desolate, monotonous planet for our children, grandchildren, and more generations than we can imagine. We will also undermine ecosystem functions (e.g., pollination which is critical for food production) and ecosystem resilience (when losing keystone species in food chains), as well as reduce functional diversity (critical for the ability of ecosystems to respond to shocks and stress) and genetic diversity that plays an important role for development of new medicines, materials, and sources of energy.

Coral Reef Ecosystems

Coral reefs are the most biologically diverse marine ecosystem, often described as the rainforests of the ocean. Over a million species, most not yet described [119], are estimated to populate coral reef ecosystems generating crucial ecosystem services for at least 500 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 [120], thus making the ocean more corrosive to the calcium carbonate shells (exoskeletons) of many marine organisms. Geochemical records show that ocean pH is already outside its range of the past several million years [121–122]. Warming causes coral bleaching, as overheated coral expel symbiotic algae and become vulnerable to disease and mortality [123]. 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 [40,124].

Local human-made stresses add to the global warming and acidification effects, all of these driving a contraction of 1–2% per year in the abundance of reef-building corals [39]. Loss of the three-dimensional coral reef frameworks has consequences for all the species that depend on them. 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 and intensification of storms.

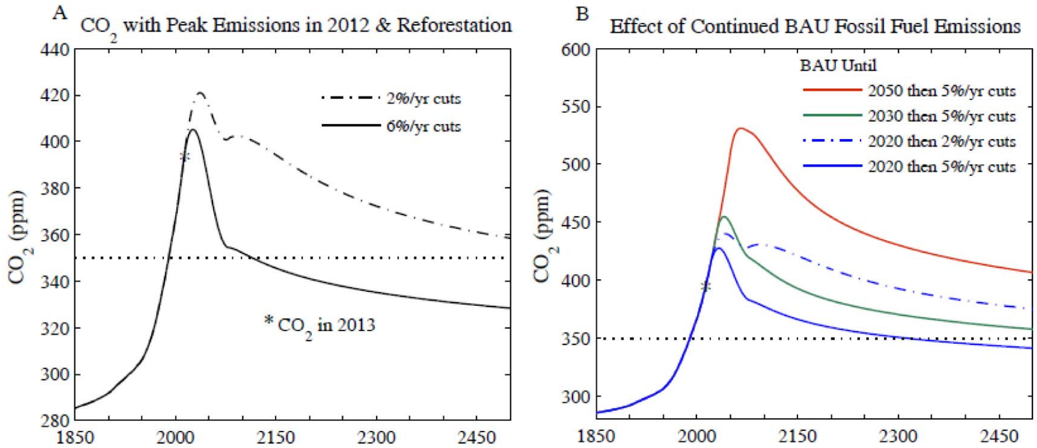

Figure 5. Atmospheric CO_2 if fossil fuel emissions reduced. (A) 6% or 2% annual cut begins in 2013 and 100 GtC reforestation drawdown occurs in 2031–2080, (B) effect of delaying onset of emission reduction.
doi:10.1371/journal.pone.0081648.g005

Climate Extremes

Changes in the frequency and magnitude of climate extremes, of both moisture and temperature, are affected by climate trends as well as changing variability. Extremes of the hydrologic cycle are expected to intensify in a warmer world. A warmer atmosphere holds more moisture, so precipitation can be heavier and cause more extreme flooding. Higher temperatures, on the other hand, increase evaporation and can intensify droughts when they occur, as can expansion of the subtropics, as discussed above. Global models for the 21st century find an increased variability of precipitation minus evaporation [P-E] in most of the world, especially near the equator and at high latitudes [125]. Some models also show an intensification of droughts in the Sahel, driven by increasing greenhouse gases [126].

Observations of ocean salinity patterns for the past 50 years reveal an intensification of [P-E] patterns as predicted by models, but at an even faster rate. Precipitation observations over land show the expected general increase of precipitation poleward of the subtropics and decrease at lower latitudes [1,26]. An increase of intense precipitation events has been found on much of the world's land area [127–129]. Evidence for widespread drought intensification is less clear and inherently difficult to confirm with available data because of the increase of time-integrated precipitation at most locations other than the subtropics. Data analyses have found an increase of drought intensity at many locations [130–131] The magnitude of change depends on the drought index employed [132], but soil moisture provides a good means to separate the effect of shifting seasonal precipitation and confirms an overall drought intensification [37].

Global warming of ~0.6°C since the 1970s (Fig. 3) has already caused a notable increase in the occurrence of extreme summer heat [46]. The likelihood of occurrence or the fractional area covered by 3-standard-deviation hot anomalies, relative to a base period (1951–1980) that was still within the range of Holocene climate, has increased by more than a factor of ten. Large areas around Moscow, the Mediterranean region, the United States and Australia have experienced such extreme anomalies in the past three years. Heat waves lasting for weeks have a devastating impact on human health: the European heat wave of summer 2003 caused over 70,000 excess deaths [133]. This heat record for Europe was surpassed already in 2010 [134]. The number of extreme heat waves has increased several-fold due to global warming [45–46,135] and will increase further if temperatures continue to rise.

Human Health

Impacts of climate change cause widespread harm to human health, with children often suffering the most. Food shortages, polluted air, contaminated or scarce supplies of water, an expanding area of vectors causing infectious diseases, and more intensely allergenic plants are among the harmful impacts [26]. More extreme weather events cause physical and psychological harm. World health experts have concluded with "very high confidence" that climate change already contributes to the global burden of disease and premature death [26].

IPCC [26] projects the following trends, if global warming continue to increase, where only trends assigned very high confidence or high confidence are included: (i) increased malnutrition and consequent disorders, including those related to child growth and development, (ii) increased death, disease and injuries from heat waves, floods, storms, fires and droughts, (iii) increased cardio-respiratory morbidity and mortality associated with ground-level ozone. While IPCC also projects fewer deaths from cold, this positive effect is far outweighed by the negative ones.

Growing awareness of the consequences of human-caused climate change triggers anxiety and feelings of helplessness [136–137]. Children, already susceptible to age-related insecurities, face additional destabilizing insecurities from questions about how they will cope with future climate change [138–139]. Exposure to media ensures that children cannot escape hearing that their future and that of other species is at stake, and that the window of opportunity to avoid dramatic climate impacts is closing. The psychological health of our children is a priority, but denial of the truth exposes our children to even greater risk.

Health impacts of climate change are in addition to direct effects of air and water pollution. A clear illustration of direct effects of fossil fuels on human health was provided by an inadvertent experiment in China during the 1950–1980 period of central planning, when free coal for winter heating was provided to North China but not to the rest of the country. Analysis of the impact was made [140] using the most comprehensive data file ever compiled on mortality and air pollution in any developing country. A principal conclusion was that the 500 million residents of North China experienced during the 1990s a loss of more than 2.5 billion life years owing to the added air pollution, and an average reduction in life expectancy of 5.5 years. The degree of air pollution in China exceeded that in most of the world, yet assessments of total health effects must also include other fossil fuel caused air and water pollutants, as discussed in the following section on ecology and the environment.

The Text S1 has further discussion of health impacts of climate change.

Ecology and the Environment

The ecological impact of fossil fuel mining increases as the largest, easiest to access, resources are depleted [141]. A constant fossil fuel production rate requires increasing energy input, but also use of more land, water, and diluents, with the production of more waste [142]. The increasing ecological and environmental impact of a given amount of useful fossil fuel energy is a relevant consideration in assessing alternative energy strategies.

Coal mining has progressively changed from predominantly underground mining to surface mining [143], including mountaintop removal with valley fill, which is now widespread in the Appalachian ecoregion in the United States. Forest cover and topsoil are removed, explosives are used to break up rocks to access coal, and the excess rock is pushed into adjacent valleys, where it buries existing streams. Burial of headwater streams causes loss of ecosystems that are important for nutrient cycling and production of organic matter for downstream food webs [144]. The surface alterations lead to greater storm runoff [145] with likely impact on downstream flooding. Water emerging from valley fills contain toxic solutes that have been linked to declines in watershed biodiversity [146]. Even with mine-site reclamation intended to restore pre-mined surface conditions, mine-derived chemical constituents are found in domestic well water [147]. Reclaimed areas, compared with unmined areas, are found to have increased soil density with decreased organic and nutrient content, and with reduced water infiltration rates [148]. Reclaimed areas have been found to produce little if any regrowth of woody vegetation even after 15 years [149], and, although this deficiency might be addressed via more effective reclamation methods, there remains a likely significant loss of carbon storage [149].

Oil mining has an increasing ecological footprint per unit delivered energy because of the decreasing size of new fields and their increased geographical dispersion; transit distances are greater and wells are deeper, thus requiring more energy input [145]. Useful quantitative measures of the increasing ecological impacts are provided by the history of oil development in Alberta, Canada for production of both conventional oil and tar sands development. The area of land required per barrel of produced oil increased by a factor of 12 between 1955 and 2006 [150] leading to ecosystem fragmentation by roads and pipelines needed to support the wells [151]. Additional escalation of the mining impact occurs as conventional oil mining is supplanted by tar sands development, with mining and land disturbance from the latter producing land use-related greenhouse gas emissions as much as 23 times greater than conventional oil production per unit area [152], but with substantial variability and uncertainty [152–153]. Much of the tar sands bitumen is extracted through surface mining that removes the "overburden" (i.e., boreal forest ecosystems) and tar sand from large areas to a depth up to 100 m, with ecological impacts downstream and in the mined area [154]. Although mined areas are supposed to be reclaimed, as in the case of mountaintop removal, there is no expectation that the ecological value of reclaimed areas will be equivalent to predevelopment condition [141,155]. Landscape changes due to tar sands mining and reclamation cause a large loss of peatland and stored carbon, while also significantly reducing carbon sequestration potential [156]. Lake sediment cores document increased chemical pollution of ecosystems during the past several decades traceable to tar sands development [157] and snow and water samples indicate that recent levels of numerous pollutants exceeded local and national criteria for protection of aquatic organisms [158].

Gas mining by unconventional means has rapidly expanded in recent years, without commensurate understanding of the ecological, environmental and human health consequences [159]. The predominant approach is hydraulic fracturing ("fracking") of deep shale formations via injection of millions of gallons of water, sand and toxic chemicals under pressure, thus liberating methane [155,160]. A large fraction of the injected water returns to the surface as wastewater containing high concentrations of heavy metals, oils, greases and soluble organic compounds [161]. Management of this wastewater is a major technical challenge, especially because the polluted waters can continue to backflow from the wells for many years [161]. Numerous instances of groundwater and river contamination have been cited [162]. High levels of methane leakage from fracking have been found [163], as well as nitrogen oxides and volatile organic compounds [159]. Methane leaks increase the climate impact of shale gas, but whether the leaks are sufficient to significantly alter the climate forcing by total natural gas development is uncertain [164]. Overall, environmental and ecologic threats posed by unconventional gas extraction are uncertain because of limited research, however evidence for groundwater pollution on both local and river basin scales is a major concern [165].

Today, with cumulative carbon emissions ~370 GtC from all fossil fuels, we are at a point of severely escalating ecological and environmental impacts from fossil fuel use and fossil fuel mining, as is apparent from the mountaintop removal for coal, tar sands extraction of oil, and fracking for gas. The ecological and environmental implications of scenarios with carbon emissions of 1000 GtC or greater, as discussed below, would be profound and should influence considerations of appropriate energy strategies.

Summary: Climate Impacts

Climate impacts accompanying global warming of 2°C or more would be highly deleterious. Already there are numerous indications of substantial effects in response to warming of the past few decades. That warming has brought global temperature close to if not slightly above the prior range of the Holocene. We conclude that an appropriate target would be to keep global temperature at a level within or close to the Holocene range. Global warming of 2°C would be well outside the Holocene range and far into the dangerous range.

Transient Climate Change

We must quantitatively relate fossil fuel emissions to global temperature in order to assess how rapidly fossil fuel emissions must be phased down to stay under a given temperature limit. Thus we must deal with both a transient carbon cycle and transient global climate change.

Global climate fluctuates stochastically and also responds to natural and human-made climate forcings [1,166]. Forcings, measured in W/m^2 averaged over the globe, are imposed perturbations of Earth's energy balance caused by changing forcing agents such as solar irradiance and human-made greenhouse gases (GHGs). CO_2 accounts for more than 80% of the added GHG forcing in the past 15 years [64,167] and, if fossil fuel emissions continue at a high level, CO_2 will be the dominant driver of future global temperature change.

We first define our method of calculating atmospheric CO_2 as a function of fossil fuel emissions. We then define our assumptions about the potential for drawing down atmospheric CO_2 via reforestation and increase of soil carbon, and we define fossil fuel emission reduction scenarios that we employ in our study. Finally we describe all forcings employed in our calculations of global temperature and the method used to simulate global temperature.

Carbon Cycle and Atmospheric CO_2

The carbon cycle defines the fate of CO_2 injected into the air by fossil fuel burning [1,168] as the additional CO_2 distributes itself over time among surface carbon reservoirs: the atmosphere, ocean, soil, and biosphere. We use the dynamic-sink pulse-response function version of the well-tested Bern carbon cycle model [169], as described elsewhere [54,170].

Specifically, we solve equations 3–6, 16–17, A.2.2, and A.3 of Joos et al. [169] using the same parameters and assumptions therein, except that initial (1850) atmospheric CO_2 is assumed to be 285.2 ppm [167]. Historical fossil fuel CO_2 emissions are from Boden et al. [5]. This Bern model incorporates non-linear ocean chemistry feedbacks and CO_2 fertilization of the terrestrial biosphere, but it omits climate-carbon feedbacks, e.g., assuming static global climate and ocean circulation. Therefore our results should be regarded as conservative, especially for scenarios with large emissions.

A pulse of CO_2 injected into the air decays by half in about 25 years as CO_2 is taken up by the ocean, biosphere and soil, but nearly one-fifth is still in the atmosphere after 500 years (Fig. 4A). Eventually, over hundreds of millennia, weathering of rocks will deposit all of this initial CO_2 pulse on the ocean floor as carbonate sediments [168].

Under equilibrium conditions a negative CO_2 pulse, i.e., artificial extraction and storage of some CO_2 amount, decays at about the same rate as a positive pulse (Fig. 4A). Thus if it is decided in the future that CO_2 must be extracted from the air and removed from the carbon cycle (e.g., by storing it underground or in carbonate bricks), the impact on atmospheric CO_2 amount will diminish in time. This occurs because carbon is exchanged among the surface carbon reservoirs as they move toward an equilibrium distribution, and thus, e.g., CO_2 out-gassing by the ocean can offset some of the artificial drawdown. The CO_2 extraction required to reach a given target atmospheric CO_2 level therefore depends on the prior emission history and target timeframe, but the amount that must be extracted substantially exceeds the net reduction of the atmospheric CO_2 level that will be achieved. We clarify this matter below by means of specific scenarios for capture of CO_2.

It is instructive to see how fast atmospheric CO_2 declines if fossil fuel emissions are instantly terminated (Fig. 4B). Halting emissions in 2015 causes CO_2 to decline to 350 ppm at century's end (Fig. 4B). A 20 year delay in halting emissions has CO_2 returning to 350 ppm at about 2300. With a 40 year delay, CO_2 does not return to 350 ppm until after 3000. These results show how difficult it is to get back to 350 ppm if emissions continue to grow for even a few decades.

These results emphasize the urgency of initiating emissions reduction [171]. As discussed above, keeping global climate close to the Holocene range requires a long-term atmospheric CO_2 level of about 350 ppm or less, with other climate forcings similar to today's levels. If emissions reduction had begun in 2005, reduction at 3.5%/year would have achieved 350 ppm at 2100. Now the requirement is at least 6%/year. Delay of emissions reductions until 2020 requires a reduction rate of 15%/year to achieve 350 ppm in 2100. If we assume only 50 GtC reforestation, and begin emissions reduction in 2013, the required reduction rate becomes about 9%/year.

Reforestation and Soil Carbon

Of course fossil fuel emissions will not suddenly terminate. Nevertheless, it is not impossible to return CO_2 to 350 ppm this century. Reforestation and increase of soil carbon can help draw down atmospheric CO_2. Fossil fuels account for ~80% of the CO_2 increase from preindustrial time, with land use/deforestation accounting for 20% [1,170,172–173]. Net deforestation to date is estimated to be 100 GtC (gigatons of carbon) with ±50% uncertainty [172].

Complete restoration of deforested areas is unrealistic, yet 100 GtC carbon drawdown is conceivable because: (1) the human-enhanced atmospheric CO_2 level increases carbon uptake by some vegetation and soils, (2) improved agricultural practices can convert agriculture from a CO_2 ource into a CO_2 sink [174], (3) biomass-burning power plants with CO_2 capture and storage can contribute to CO_2 drawdown.

Forest and soil storage of 100 GtC is challenging, but has other benefits. Reforestation has been successful in diverse places [175]. Minimum tillage with biological nutrient recycling, as opposed to plowing and chemical fertilizers, could sequester 0.4–1.2 GtC/year [176] while conserving water in soils, building agricultural resilience to climate change, and increasing productivity especially in smallholder rain-fed agriculture, thereby reducing expansion of agriculture into forested ecosystems [177–178]. Net tropical deforestation may have decreased in the past decade [179], but because of extensive deforestation in earlier decades [170,172–173,180–181] there is a large amount of land suitable for reforestation [182].

Use of bioenergy to draw down CO_2 should employ feedstocks from residues, wastes, and dedicated energy crops that do not compete with food crops, thus avoiding loss of natural ecosystems and cropland [183–185]. Reforestation competes with agricultural land use; land needs could decline by reducing use of animal products, as livestock now consume more than half of all crops [186].

Our reforestation scenarios assume that today's net deforestation rate (~1 GtC/year; see [54]) will stay constant until 2020, then linearly decrease to zero by 2030, followed by sinusoidal 100 GtC biospheric carbon storage over 2031–2080. Alternative timings do not alter conclusions about the potential to achieve a given CO_2 level such as 350 ppm.

Emission Reduction Scenarios

A 6%/year decrease of fossil fuel emissions beginning in 2013, with 100 GtC reforestation, achieves a CO_2 decline to 350 ppm near the end of this century (Fig. 5A). Cumulative fossil fuel emissions in this scenario are ~129 GtC from 2013 to 2050, with an additional 14 GtC by 2100. If our assumed land use changes occur a decade earlier, CO_2 returns to 350 ppm several years earlier; however that has negligible effect on the maximum global temperature calculated below.

Delaying fossil fuel emission cuts until 2020 (with 2%/year emissions growth in 2012–2020) causes CO_2 to remain above 350 ppm (with associated impacts on climate) until 2300 (Fig. 5B). If reductions are delayed until 2030 or 2050, CO_2 remains above 350 ppm or 400 ppm, respectively, until well after 2500.

We conclude that it is urgent that large, long-term emission reductions begin soon. Even if a 6%/year reduction rate and 500 GtC are not achieved, it makes a huge difference when reductions begin. There is no practical justification for why emissions necessarily must even approach 1000 GtC.

Climate Forcings

Atmospheric CO_2 and other GHGs have been well-measured for the past half century, allowing accurate calculation of their climate forcing. The growth rate of the GHG forcing has declined moderately since its peak values in the 1980s, as the growth rate of CH_4 and chlorofluorocarbons has slowed [187]. Annual changes of CO_2 are highly correlated with the El Niño cycle (Fig. 6). Two strong La Niñas in the past five years have depressed CO_2 growth as well as the global warming rate (Fig. 3). The CO_2 growth rate and warming rate can be expected to increase as we move into the next El Niño, with the CO_2 growth already reaching 3 ppm/year in mid-2013 [188]. The CO_2 climate forcing does not increase as rapidly as the CO_2 amount because of partial saturation of CO_2 absorption bands [75]. The GHG forcing is now increasing at a rate of almost 0.4 W/m^2 per decade [187].

Solar irradiance variations are sometimes assumed to be the most likely natural driver of climate change. Solar irradiance has been measured from satellites since the late 1970s (Fig. 7). These data are from a composite of several satellite-measured time series. Data through 28 February 2003 are from [189] and Physikalisch Meteorologisches Observatorium Davos, World Radiation Center. Subsequent update is from University of Colorado Solar Radiation & Climate Experiment (SORCE). Data sets are concatenated by matching the means over the first 12 months of SORCE data. Monthly sunspot numbers (Fig. 7) support the conclusion that the solar irradiance in the current solar cycle is significantly lower than in the three preceding solar cycles. Amplification of the direct solar forcing is conceivable, e.g., through effects on ozone or atmospheric condensation nuclei, but empirical data place a factor of two upper limit on the amplification, with the most likely forcing in the range 100–120% of the directly measured solar irradiance change [64].

Recent reduced solar irradiance (Fig. 7) may have decreased the forcing over the past decade by about half of the full amplitude of measured irradiance variability, thus yielding a negative forcing of, say, − 0.12 W/m^2. This compares with a decadal increase of the GHG forcing that is positive and about three times larger in magnitude. Thus the solar forcing is not negligible and might partially account for the slowdown in global warming in the past decade [17]. However, we must (1) compare the solar forcing with the net of other forcings, which enhances the importance of solar change, because the net forcing is smaller than the GHG forcing, and (2) consider forcing changes on longer time scales, which greatly diminishes the importance of solar change, because solar variability is mainly oscillatory.

Human-made tropospheric aerosols, which arise largely from fossil fuel use, cause a substantial negative forcing. As noted above, two independent analyses [64,72] yield a total (direct plus indirect) aerosol forcing in the past decade of about −1.5 W/m^2, half the magnitude of the GHG forcing and opposite in sign. That empirical aerosol forcing assessment for the past decade is consistent with the climate forcings scenario (Fig. 8) that we use for the past century in the present and prior studies [64,190]. Supplementary Table S1 specifies the historical forcings and Table S2 gives several scenarios for future forcings.

Future Climate Forcings

Future global temperature change should depend mainly on atmospheric CO_2, at least if fossil fuel emissions remain high. Thus to provide the clearest picture of the CO_2 effect, we approximate the net future change of human-made non-CO_2 forcings as zero and we exclude future changes of natural climate forcings, such as solar irradiance and volcanic aerosols. Here we discuss possible effects of these approximations.

Uncertainties in non-CO_2 forcings concern principally solar, aerosol and other GHG forcings. Judging from the sunspot numbers (Fig. 7B and [191]) for the past four centuries, the current solar cycle is almost as weak as the Dalton Minimum of the late 18th century. Conceivably irradiance could decline further to the level of the Maunder Minimum of the late 17th century [192–193]. For our simulation we choose an intermediate path between recovery to the level before the current solar cycle and decline to a still lower level. Specifically, we keep solar irradiance fixed at the reduced level of 2010, which is probably not too far off in either direction. Irradiance in 2010 is about 0.1 W/m^2 less than the mean of the prior three solar cycles, a decrease of forcing that

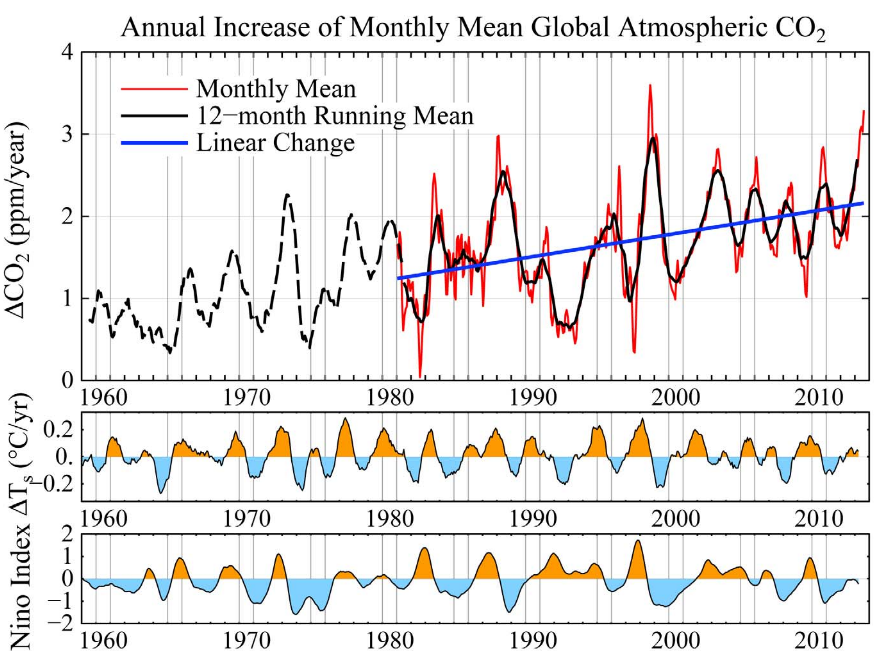

Figure 6. Annual increase of CO_2 based on data from the NOAA Earth System Research Laboratory [188]. Prior to 1981 the CO_2 change is based on only Mauna Loa, Hawaii. Temperature changes in lower diagram are 12-month running means for the globe and Niño3.4 area [16].
doi:10.1371/journal.pone.0081648.g006

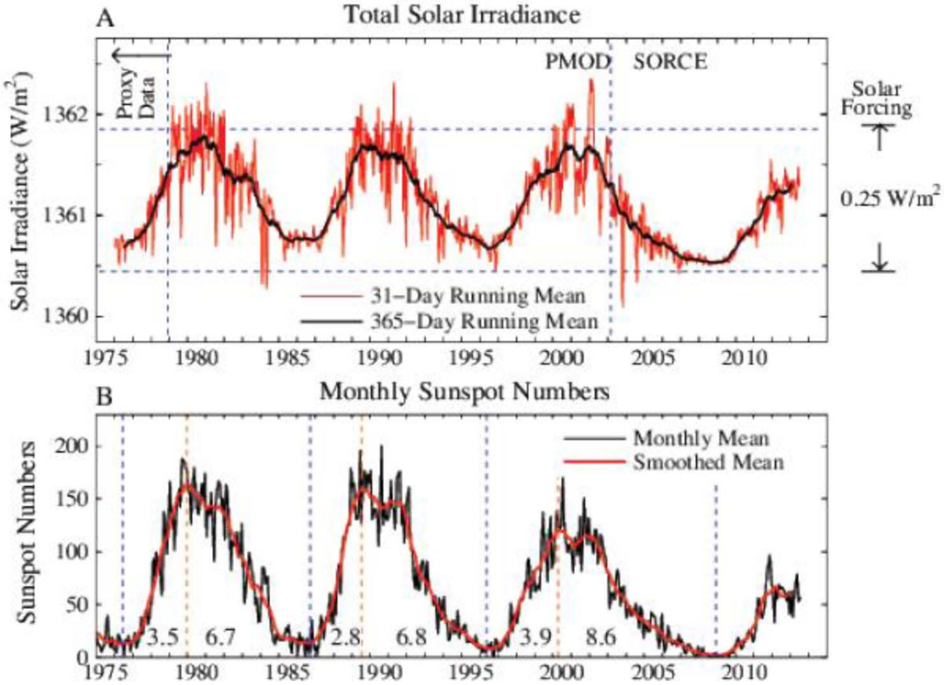

Figure 7. Solar irradiance and sunspot number in the era of satellite data (see text). Left scale is the energy passing through an area perpendicular to Sun-Earth line. Averaged over Earth's surface the absorbed solar energy is ~240 W/m^2, so the full amplitude of measured solar variability is ~0.25 W/m^2.
doi:10.1371/journal.pone.0081648.g007

would be restored by the CO_2 increase within 3–4 years at its current growth rate. Extensive simulations [17,194] confirm that the effect of solar variability is small compared with GHGs if CO_2 emissions continue at a high level. However, solar forcing can affect the magnitude and detection of near-term warming. Also, if rapidly declining GHG emissions are achieved, changes of solar forcing will become relatively more important.

Aerosols present a larger uncertainty. Expectations of decreases in large source regions such as China [195] may be counteracted by aerosol increases other places as global population continues to increase. Our assumption of unchanging human-made aerosols could be substantially off in either direction. For the sake of interpreting on-going and future climate change it is highly desirable to obtain precise monitoring of the global aerosol forcing [73].

Non-CO_2 GHG forcing has continued to increase at a slow rate since 1995 (Fig. 6 in [64]). A desire to constrain climate change may help reduce emissions of these gases in the future. However, it will be difficult to prevent or fully offset positive forcing from increasing N_2O, as its largest source is associated with food production and the world's population is continuing to rise.

On the other hand, we are also probably underestimating a negative aerosol forcing, e.g., because we have not included future volcanic aerosols. Given the absence of large volcanic eruptions in the past two decades (the last one being Mount Pinatubo in 1991), multiple volcanic eruptions would cause a cooling tendency [196] and reduce heat storage in the ocean [197].

Overall, we expect the errors due to our simple approximation of non-CO_2 forcings to be partially off-setting. Specifically, we have likely underestimated a positive forcing by non-CO_2 GHGs, while also likely underestimating a negative aerosol forcing.

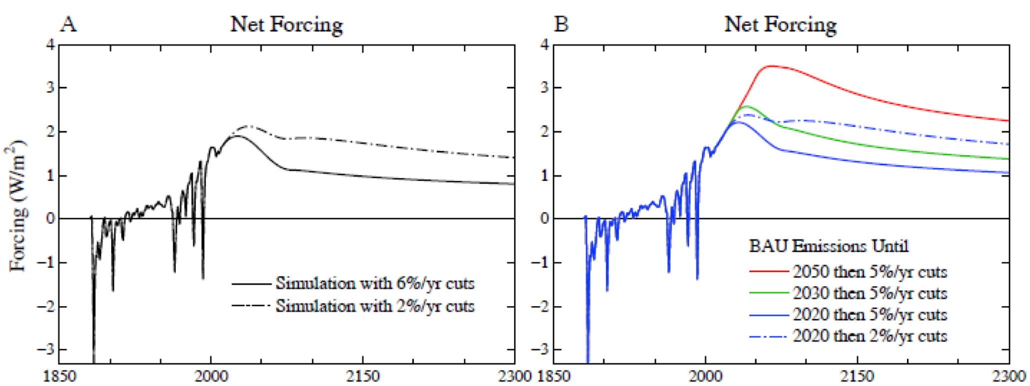

Figure 8. Climate forcings employed in our six main scenarios. Forcings through 2010 are as in [64].
doi:10.1371/journal.pone.0081648.g008

Note that uncertainty in forcings is partly obviated via the focus on Earth's energy imbalance in our analysis. The planet's energy imbalance is an integrative quantity that is especially useful for a case in which some of the forcings are uncertain or unmeasured. Earth's measured energy imbalance includes the effects of all forcings, whether they are measured or not.

Simulations of Future Global Temperature

We calculate global temperature change for a given CO_2 scenario using a climate response function (Table S3) that accurately replicates results from a global climate model with sensitivity 3°C for doubled CO_2 [64]. A best estimate of climate sensitivity close to 3°C for doubled CO_2 has been inferred from paleoclimate data [51–52]. This empirical climate sensitivity is generally consistent with that of global climate models [1], but the empirical approach makes the inferred high sensitivity more certain and the quantitative evaluation more precise. Because this climate sensitivity is derived from empirical data on how Earth responded to past changes of boundary conditions, including atmospheric composition, our conclusions about limits on fossil fuel emissions can be regarded as largely independent of climate models.

The detailed temporal and geographical response of the climate system to the rapid human-made change of climate forcings is not well-constrained by empirical data, because there is no faithful paleoclimate analog. Thus climate models necessarily play an important role in assessing practical implications of climate change. Nevertheless, it is possible to draw important conclusions with transparent computations. A simple response function (Green's function) calculation [64] yields an estimate of global mean temperature change in response to a specified time series for global climate forcing. This approach accounts for the delayed response of the climate system caused by the large thermal inertia of the ocean, yielding a global mean temporal response in close accord with that obtained from global climate models.

Tables S1 and S2 in Supporting Information give the forcings we employ and Table S3 gives the climate response function for our Green's function calculation, defined by equation 2 of [64]. The Green's function is driven by the net forcing, which, with the response function, is sufficient information for our results to be reproduced. However, we also include the individual forcings in Table S1, in case researchers wish to replace specific forcings or use them for other purposes.

Simulated global temperature (Fig. 9) is for CO_2 scenarios of Fig. 5. Peak global warming is ~1.1°C, declining to less than 1°C by mid-century, if CO_2 emissions are reduced 6%/year beginning in 2013. In contrast, warming reaches 1.5°C and stays above 1°C until after 2400 if emissions continue to increase until 2030, even though fossil fuel emissions are phased out rapidly (5%/year) after 2030 and 100 GtC reforestation occurs during 2030–2080. If emissions continue to increase until 2050, simulated warming exceeds 2°C well into the 22^{nd} century.

Increased global temperature persists for many centuries after the climate forcing declines, because of the thermal inertia of the ocean [198]. Some temperature reduction is possible if the climate forcing is reduced rapidly, before heat has penetrated into the deeper ocean. Cooling by a few tenths of a degree in Fig. 9 is a result mainly of the 100 GtC biospheric uptake of CO_2 during 2030–2080. Note the longevity of the warming, especially if emissions reduction is as slow as 2%/year, which might be considered to be a rapid rate of reduction.

The temporal response of the real world to the human-made climate forcing could be more complex than suggested by a simple response function calculation, especially if rapid emissions growth continues, yielding an unprecedented climate forcing scenario. For example, if ice sheet mass loss becomes rapid, it is conceivable that the cold fresh water added to the ocean could cause regional surface cooling [199], perhaps even at a point when sea level rise has only reached a level of the order of a meter [200]. However, any uncertainty in the surface thermal response this century due to such phenomena has little effect on our estimate of the dangerous level of emissions. The long lifetime of the fossil fuel carbon in the climate system and the persistence of ocean warming for millennia [201] provide sufficient time for the climate system to achieve full response to the fast feedback processes included in the 3°C climate sensitivity.

Indeed, the long lifetime of fossil fuel carbon in the climate system and persistence of the ocean warming ensure that "slow" feedbacks, such as ice sheet disintegration, changes of the global vegetation distribution, melting of permafrost, and possible release of methane from methane hydrates on continental shelves, would also have time to come into play. Given the unprecedented rapidity of the human-made climate forcing, it is difficult to establish how soon slow feedbacks will become important, but clearly slow feedbacks should be considered in assessing the "dangerous" level of global warming, as discussed in the next section.

Danger of Initiating Uncontrollable Climate Change

Our calculated global warming as a function of CO_2 amount is based on equilibrium climate sensitivity 3°C for doubled CO_2. That is the central climate sensitivity estimate from climate models [1], and it is consistent with climate sensitivity inferred from Earth's climate history [51–52]. However, this climate sensitivity includes only the effects of fast feedbacks of the climate system, such as water vapor, clouds, aerosols, and sea ice. Slow feedbacks, such as change of ice sheet area and climate-driven changes of greenhouse gases, are not included.

Slow Climate Feedbacks and Irreversible Climate Change

Excluding slow feedbacks was appropriate for simulations of the past century, because we know the ice sheets were stable then and our climate simulations used observed greenhouse gas amounts that included any contribution from slow feedbacks. However, we must include slow feedbacks in projections of warming for the 21^{st} century and beyond. Slow feedbacks are important because they affect climate sensitivity and because their instigation is related to the danger of passing "points of no return", beyond which irreversible consequences become inevitable, out of humanity's control.

Antarctic and Greenland ice sheets present the danger of change with consequences that are irreversible on time scales important to society [1]. These ice sheets required millennia to grow to their present sizes. If ice sheet disintegration reaches a point such that the dynamics and momentum of the process take over, at that point reducing greenhouse gases may be unable to prevent major ice sheet mass loss, sea level rise of many meters, and worldwide loss of coastal cities – a consequence that is irreversible for practical purposes. Interactions between the ocean and ice sheets are particularly important in determining ice sheet changes, as a warming ocean can melt the ice shelves, the tongues of ice that extend from the ice sheets into the ocean and buttress the large land-based ice sheets [92,202–203]. Paleoclimate data for sea level change indicate that sea level changed at rates of the order of a meter per century [81–83], even at times when the forcings driving climate change were far weaker than the human-

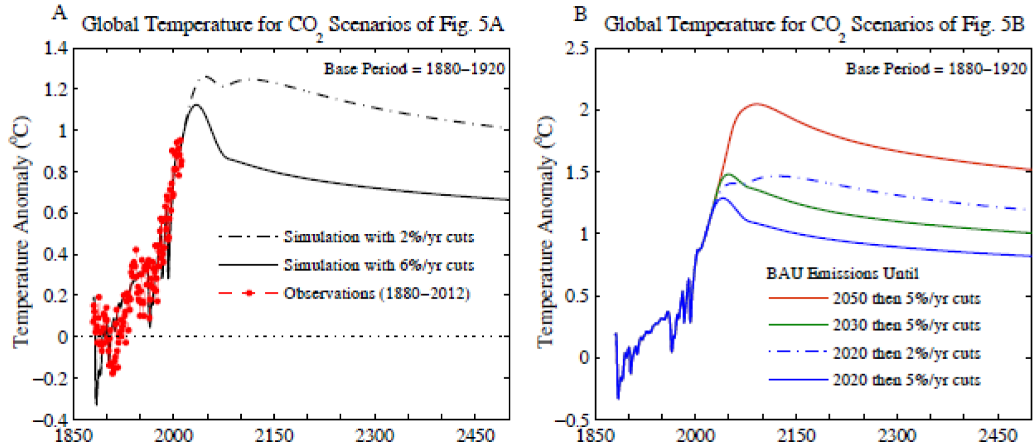

Figure 9. Simulated global temperature relative to 1880–1920 mean for CO_2 scenarios of Figure 5.
doi:10.1371/journal.pone.0081648.g009

made forcing. Thus, because ocean warming is persistent for centuries, there is a danger that large irreversible change could be initiated by excessive ocean warming.

Paleoclimate data are not as helpful for defining the likely rate of sea level rise in coming decades, because there is no known case of growth of a positive (warming) climate forcing as rapid as the anthropogenic change. The potential for unstable ice sheet disintegration is controversial, with opinion varying from likely stability of even the (marine) West Antarctic ice sheet [94] to likely rapid non-linear response extending up to multi-meter sea level rise [97–98]. Data for the modern rate of annual ice sheet mass changes indicate an accelerating rate of mass loss consistent with a mass loss doubling time of a decade or less (Fig. 10). However, we do not know the functional form of ice sheet response to a large persistent climate forcing. Longer records are needed for empirical assessment of this ostensibly nonlinear behavior.

Greenhouse gas amounts in the atmosphere, most importantly CO_2 and CH_4, change in response to climate change, i.e., as a feedback, in addition to the immediate gas changes from human-caused emissions. As the ocean warms, for example, it releases CO_2 to the atmosphere, with one principal mechanism being the simple fact that the solubility of CO_2 decreases as the water temperature rises [204]. We also include in the category of slow feedbacks the global warming spikes, or "hyperthermals", that have occurred a number of times in Earth's history during the course of slower global warming trends. The mechanisms behind these hyperthermals are poorly understood, as discussed below, but they are characterized by the injection into the surface climate system of a large amount of carbon in the form of CH_4 and/or CO_2 on the time scale of a millennium [205–207]. The average rate of injection of carbon into the climate system during these hyperthermals was slower than the present human-made injection of fossil fuel carbon, yet it was faster than the time scale for removal of carbon from the surface reservoirs via the weathering process [3,208], which is tens to hundreds of thousands of years.

Methane hydrates – methane molecules trapped in frozen water molecule cages in tundra and on continental shelves – and organic matter such as peat locked in frozen soils (permafrost) are likely mechanisms in the past hyperthermals, and they provide another climate feedback with the potential to amplify global warming if large scale thawing occurs [209–210]. Paleoclimate data reveal instances of rapid global warming, as much as 5–6°C, as a sudden additional warming spike during a longer period of gradual warming [see Text S1]. The candidates for the carbon injected into the climate system during those warmings are methane hydrates on continental shelves destabilized by sea floor warming [211] and carbon released from frozen soils [212]. As for the present, there are reports of methane release from thawing permafrost on land [213] and from sea-bed methane hydrate deposits [214], but amounts so far are small and the data are snapshots that do not prove that there is as yet a temporal increase of emissions.

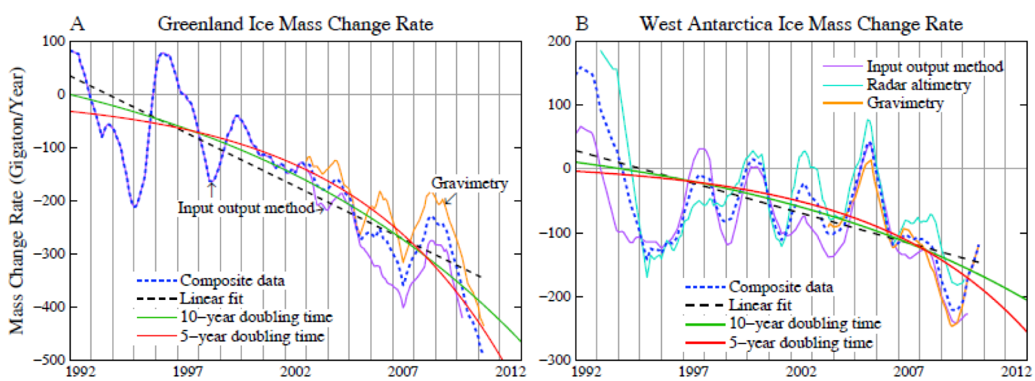

Figure 10. Annual Greenland and West Antarctic ice mass changes as estimated via alternative methods. Data were read from Figure 4 of Shepherd et al. [23] and averaged over the available records.
doi:10.1371/journal.pone.0081648.g010

There is a possibility of rapid methane hydrate or permafrost emissions in response to warming, but that risk is largely unquantified [215]. The time needed to destabilize large methane hydrate deposits in deep sediments is likely millennia [215]. Smaller but still large methane hydrate amounts below shallow waters as in the Arctic Ocean are more vulnerable; the methane may oxidize to CO_2 in the water, but it will still add to the long-term burden of CO_2 in the carbon cycle. Terrestrial permafrost emissions of CH_4 and CO_2 likely can occur on a time scale of a few decades to several centuries if global warming continues [215]. These time scales are within the lifetime of anthropogenic CO_2, and thus these feedbacks must be considered in estimating the dangerous level of global warming. Because human-made warming is more rapid than natural long-term warmings in the past, there is concern that methane hydrate or peat feedbacks could be more rapid than the feedbacks that exist in the paleoclimate record.

Climate model studies and empirical analyses of paleoclimate data can provide estimates of the amplification of climate sensitivity caused by slow feedbacks, excluding the singular mechanisms that caused the hyperthermal events. Model studies for climate change between the Holocene and the Pliocene, when Earth was about 3°C warmer, find that slow feedbacks due to changes of ice sheets and vegetation cover amplified the fast feedback climate response by 30–50% [216]. These same slow feedbacks are estimated to amplify climate sensitivity by almost a factor of two for the climate change between the Holocene and the nearly ice-free climate state that existed 35 million years ago [54].

Implication for Carbon Emissions Target

Evidence presented under Climate Impacts above makes clear that 2°C global warming would have consequences that can be described as disastrous. Multiple studies [12,198,201] show that the warming would be very long lasting. The paleoclimate record and changes underway in the Arctic and on the Greenland and Antarctic ice sheets with only today's warming imply that sea level rise of several meters could be expected. Increased climate extremes, already apparent at 0.8°C warming [46], would be more severe. Coral reefs and associated species, already stressed with current conditions [40], would be decimated by increased acidification, temperature and sea level rise. More generally, humanity and nature, the modern world as we know it, is adapted to the Holocene climate that has existed more than 10,000 years. Warming of 1°C relative to 1880–1920 keeps global temperature close to the Holocene range, but warming of 2°C, to at least the Eemian level, could cause major dislocations for civilization.

However, distinctions between pathways aimed at ~1°C and 2°C warming are much greater and more fundamental than the numbers 1°C and 2°C themselves might suggest. These fundamental distinctions make scenarios with 2°C or more global warming far more dangerous; so dangerous, we suggest, that aiming for the 2°C pathway would be foolhardy.

First, most climate simulations, including ours above and those of IPCC [1], do not include slow feedbacks such as reduction of ice sheet size with global warming or release of greenhouse gases from thawing tundra. These exclusions are reasonable for a ~1°C scenario, because global temperature barely rises out of the Holocene range and then begins to subside. In contrast, global warming of 2°C or more is likely to bring slow feedbacks into play. Indeed, it is slow feedbacks that cause long-term climate sensitivity to be high in the empirical paleoclimate record [51–52]. The lifetime of fossil fuel CO_2 in the climate system is so long that it must be assumed that these slow feedbacks will occur if temperature rises well above the Holocene range.

Second, scenarios with 2°C or more warming necessarily imply expansion of fossil fuels into sources that are harder to get at, requiring greater energy using extraction techniques that are increasingly invasive, destructive and polluting. Fossil fuel emissions through 2012 total ~370 GtC (Fig. 2). If subsequent emissions decrease 6%/year, additional emissions are ~130 GtC, for a total ~500 GtC fossil fuel emissions. This 130 GtC can be obtained mainly from the easily extracted conventional oil and gas reserves (Fig. 2), with coal use rapidly phased out and unconventional fossil fuels left in the ground. In contrast, 2°C scenarios have total emissions of the order of 1000 GtC. The required additional fossil fuels will involve exploitation of tar sands, tar shale, hydrofracking for oil and gas, coal mining, drilling in the Arctic, Amazon, deep ocean, and other remote regions, and possibly exploitation of methane hydrates. Thus 2°C scenarios result in more CO_2 per unit useable energy, release of substantial CH_4 via the mining process and gas transportation, and release of CO_2 and other gases via destruction of forest "overburden" to extract subterranean fossil fuels.

Third, with our ~1°C scenario it is more likely that the biosphere and soil will be able to sequester a substantial portion of the anthropogenic fossil fuel CO_2 carbon than in the case of 2°C or more global warming. Empirical data for the CO_2 "airborne fraction", the ratio of observed atmospheric CO_2 increase divided by fossil fuel CO_2 emissions, show that almost half of the emissions is being taken up by surface (terrestrial and ocean) carbon reservoirs [187], despite a substantial but poorly measured contribution of anthropogenic land use (deforestation and agriculture) to airborne CO_2 [179,216]. Indeed, uptake of CO_2 by surface reservoirs has at least kept pace with the rapid growth of emissions [187]. Increased uptake in the past decade may be a consequence of a reduced rate of deforestation [217] and fertilization of the biosphere by atmospheric CO_2 and nitrogen deposition [187]. With the stable climate of the ~1°C scenario it is plausible that major efforts in reforestation and improved agricultural practices [15,173,175–177], with appropriate support provided to developing countries, could take up an amount of carbon comparable to the 100 GtC in our ~1°C scenario. On the other hand, with warming of 2°C or more, carbon cycle feedbacks are expected to lead to substantial additional atmospheric CO_2 [218–219], perhaps even making the Amazon rainforest a source of CO_2 [219–220].

Fourth, a scenario that slows and then reverses global warming makes it possible to reduce other greenhouse gases by reducing their sources [75,221]. The most important of these gases is CH_4, whose reduction in turn reduces tropospheric O_3 and stratospheric H_2O. In contrast, chemistry modeling and paleoclimate records [222] show that trace gases increase with global warming, making it unlikely that overall atmospheric CH_4 will decrease even if a decrease is achieved in anthropogenic CH_4 sources. Reduction of the amount of atmospheric CH_4 and related gases is needed to counterbalance expected forcing from increasing N_2O and decreasing sulfate aerosols.

Now let us compare the 1°C (500 GtC fossil fuel emissions) and the 2°C (1000 GtC fossil fuel emissions) scenarios. Global temperature in 2100 would be close to 1°C in the 500 GtC scenario, and it is less than 1°C if 100 GtC uptake of carbon by the biosphere and soil is achieved via improved agricultural and forestry practices (Fig. 9). In contrast, the 1000 GtC scenario, although nominally designed to yield a fast-feedback climate response of ~ 2°C, would yield a larger eventual warming because of slow feedbacks, probably at least 3°C.

Danger of Uncontrollable Consequences

Inertia of the climate system reduces the near-term impact of human-made climate forcings, but that inertia is not necessarily our friend. One implication of the inertia is that climate impacts "in the pipeline" may be much greater than the impacts that we presently observe. Slow climate feedbacks add further danger of climate change running out of humanity's control. The response time of these slow feedbacks is uncertain, but there is evidence that some of these feedbacks already are underway, at least to a minor degree. Paleoclimate data show that on century and millennial time scales the slow feedbacks are predominately amplifying feedbacks.

The inertia of energy system infrastructure, i.e., the time required to replace fossil fuel energy systems, will make it exceedingly difficult to avoid a level of atmospheric CO_2 that would eventually have highly undesirable consequences. The danger of uncontrollable and irreversible consequences necessarily raises the question of whether it is feasible to extract CO_2 from the atmosphere on a large enough scale to affect climate change.

Carbon Extraction

We have shown that extraordinarily rapid emission reductions are needed to stay close to the 1°C scenario. In absence of extraordinary actions, it is likely that growing climate disruptions will lead to a surge of interest in "geo-engineering" designed to minimize human-made climate change [223]. Such efforts must remove atmospheric CO_2, if they are to address direct CO_2 effects such as ocean acidification as well as climate change. Schemes such as adding sulfuric acid aerosols to the stratosphere to reflect sunlight [224], an attempt to mask one pollutant with another, is a temporary band-aid for a problem that will last for millennia; besides it fails to address ocean acidification and may have other unintended consequences [225].

Potential for Carbon Extraction

At present there are no proven technologies capable of large-scale air capture of CO_2. It has been suggested that, with strong research and development support and industrial scale pilot projects sustained over decades, costs as low as ~$500/tC may be achievable [226]. Thermodynamic constraints [227] suggest that this cost estimate may be low. An assessment by the American Physical Society [228] argues that the lowest currently achievable cost, using existing approaches, is much greater ($600/t$CO_2$ or $2200/tC).

The cost of capturing 50 ppm of CO_2, at $500/tC (~$135/tCO_2), 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 will ultimately be less than 50 ppm for the reasons discussed above. For example, let us consider the scenario of Fig. 5B in which emissions continue to increase until 2030 before decreasing at 5%/year – this scenario yields atmospheric CO_2 of 410 ppm in 2100. Using our carbon cycle model we calculate that if we extract 100 ppm of CO_2 from the air over the period 2030–2100 (10/7 ppm per year), say storing that CO_2 in carbonate bricks, the atmospheric CO_2 amount in 2100 will be reduced 52 ppm to 358 ppm, i.e., the reduction of airborne CO_2 is about half of the amount extracted from the air and stored. The estimated cost of this 52 ppm CO_2 reduction is $100–400 trillion.

The cost of CO_2 capture and storage conceivably may decline in the future. Yet the practicality of carrying out such a program with alacrity in response to a climate emergency is dubious. Thus it may be appropriate to add a CO_2 removal cost to the current price of fossil fuels, which would both reduce ongoing emissions and provide resources for future cleanup.

Responsibility for Carbon Extraction

We focus on fossil fuel carbon, because of its long lifetime in the carbon cycle. Reversing the effects of deforestation is also important and there will need to be incentives to achieve increased carbon storage in the biosphere and soil, but the crucial requirement now is to limit the amount of fossil fuel carbon in the air.

The high cost of carbon extraction naturally raises the question of responsibility for excess fossil fuel CO_2 in the air. China has the largest CO_2 emissions today (Fig. 11A), but the global warming effect is closely proportional to cumulative emissions [190]. The United States is responsible for about one-quarter of cumulative emissions, with China next at about 10% (Fig. 11B). Cumulative responsibilities change rather slowly (compare Fig. 10 of 190). Estimated per capita emissions (Fig. 12) are based on population estimates for 2009–2011.

Various formulae might be devised to assign costs of CO_2 air capture, should removal prove essential for maintaining acceptable climate. For the sake of estimating the potential cost, let us assume that it proves necessary to extract 100 ppm of CO_2 (yielding a reduction of airborne CO_2 of about 50 ppm) and let us assign each country the responsibility to clean up its fraction of cumulative emissions. Assuming a cost of $500/tC (~$135/tCO_2) yields a cost of $28 trillion for the United States, about $90,000 per individual. Costs would be slightly higher for a UK citizen, but less for other nations (Fig. 12B).

Cost of CO_2 capture might decline, but the cost estimate used is more than a factor of four smaller than estimated by the American Physical Society [228] and 50 ppm is only a moderate reduction. The cost should also include safe permanent disposal of the captured CO_2, which is a substantial mass. For the sake of scaling the task, note that one GtC, made into carbonate bricks, would produce the volume of ~3000 Empire State buildings or ~1200 Great Pyramids of Giza. Thus the 26 ppm assigned to the United States, if made into carbonate bricks, would be equivalent to the stone in 165,000 Empire State buildings or 66,000 Great Pyramids of Giza. This is not intended as a practical suggestion: carbonate bricks are not a good building material, and the transport and construction costs would be additional.

The point of this graphic detail is to make clear the magnitude of the cleanup task and potential costs, if fossil fuel emissions continue unabated. More useful and economic ways of removing CO_2 may be devised with the incentive of a sufficient carbon price. For example, a stream of pure CO_2 becomes available for capture and storage if biomass is used as the fuel for power plants or as feedstock for production of liquid hydrocarbon fuels. Such clean energy schemes and improved agricultural and forestry practices are likely to be more economic than direct air capture of CO_2, but they must be carefully designed to minimize undesirable impacts and the amount of CO_2 that can be extracted on the time scale of decades will be limited, thus emphasizing the need to limit the magnitude of the cleanup task.

Policy Implications

Human-made climate change concerns physical sciences, but leads to implications for policy and politics. Conclusions from the physical sciences, such as the rapidity with which emissions must be reduced to avoid obviously unacceptable consequences and the long lag between emissions and consequences, lead to implications in social sciences, including economics, law and ethics. Intergov-

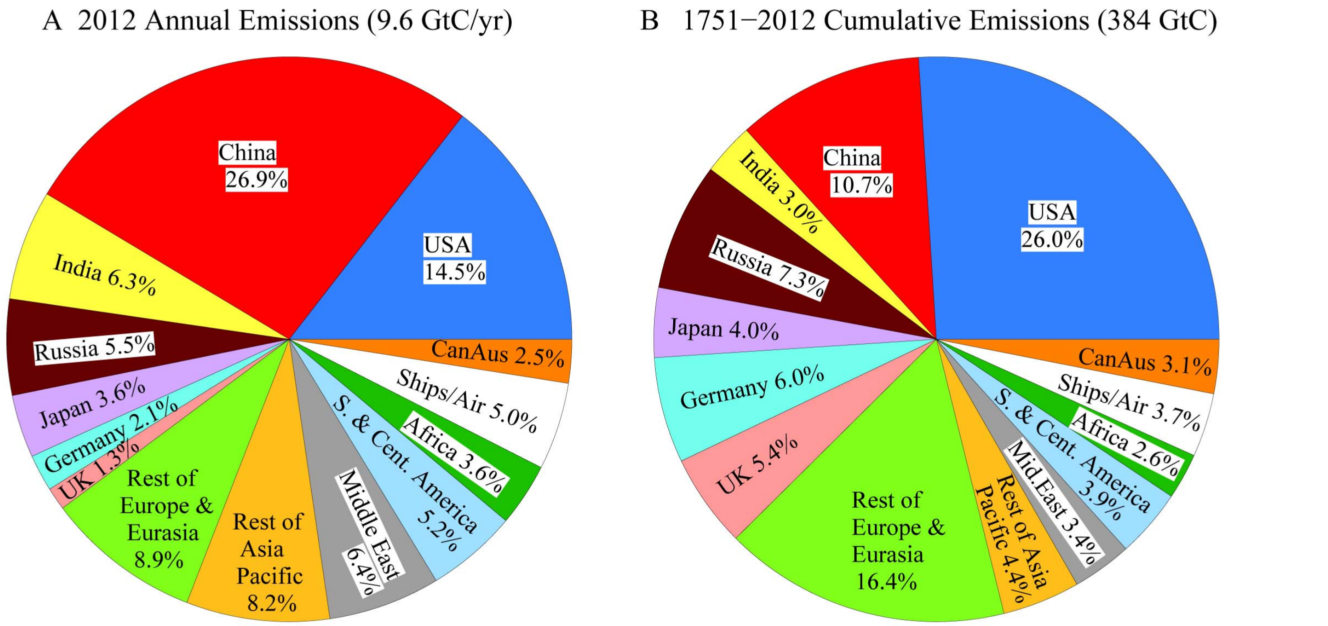

Figure 11. Fossil fuel CO_2 emissions. (A) 2012 emissions by source region, and (B) cumulative 1751–2012 emissions. Results are an update of Fig. 10 of [190] using data from [5].

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ernmental climate assessments [1,14] purposely are not policy prescriptive. Yet there is also merit in analysis and discussion of the full topic through the objective lens of science, i.e., "connecting the dots" all the way to policy implications.

Energy and Carbon Pathways: A Fork in the Road

The industrial revolution began with wood being replaced by coal as the primary energy source. Coal provided more concentrated energy, and thus was more mobile and effective. We show data for the United States (Fig. 13) because of the availability of a long data record that includes wood [229]. More limited global records yield a similar picture [Fig. 14], the largest difference being global coal now at ~30% compared with ~20% in the United States. Economic progress and wealth generation were further spurred in the twentieth century by expansion into liquid and gaseous fossil fuels, oil and gas being transported and burned more readily than coal. Only in the latter part of the twentieth century did it become clear that long-lived combustion products from fossil fuels posed a global climate threat, as formally acknowledged in the 1992 Framework Convention on Climate Change [6]. However, efforts to slow emissions of the principal atmospheric gas driving climate change, CO_2, have been ineffectual so far (Fig. 1).

Consequently, at present, as the most easily extracted oil and gas reserves are being depleted, we stand at a fork in the road to our energy and carbon future. Will we now feed our energy needs by pursuing difficult to extract fossil fuels, or will we pursue energy policies that phase out carbon emissions, moving on to the post fossil fuel era as rapidly as practical?

This is not the first fork encountered. Most nations agreed to the Framework Convention on Climate Change in 1992 [6]. Imagine if a bloc of countries favoring action had agreed on a common gradually rising carbon fee collected within each of country at domestic mines and ports of entry. Such nations might place equivalent border duties on products from nations not having a carbon fee and they could rebate fees to their domestic industry for export products to nations without an equivalent carbon fee. The legality of such a border tax adjustment under international trade law is untested, but is considered to be plausibly consistent with trade principles [230]. As the carbon fee gradually rose and as additional nations, for their own benefit, joined this bloc of nations, development of carbon-free energies and energy efficiency would have been spurred. If the carbon fee had begun in 1995, we

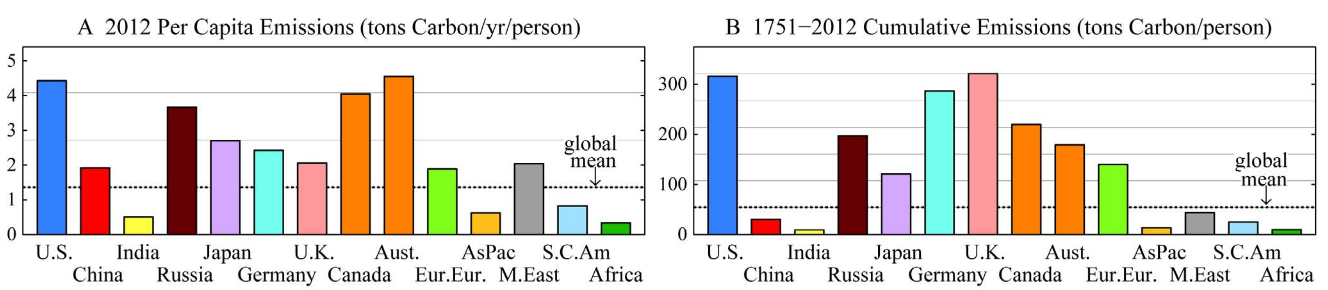

Figure 12. Per capita fossil fuel CO_2 emissions. Countries, regions and data sources are the same as in Fig. 11. Horizontal lines are the global mean and multiples of the global mean.

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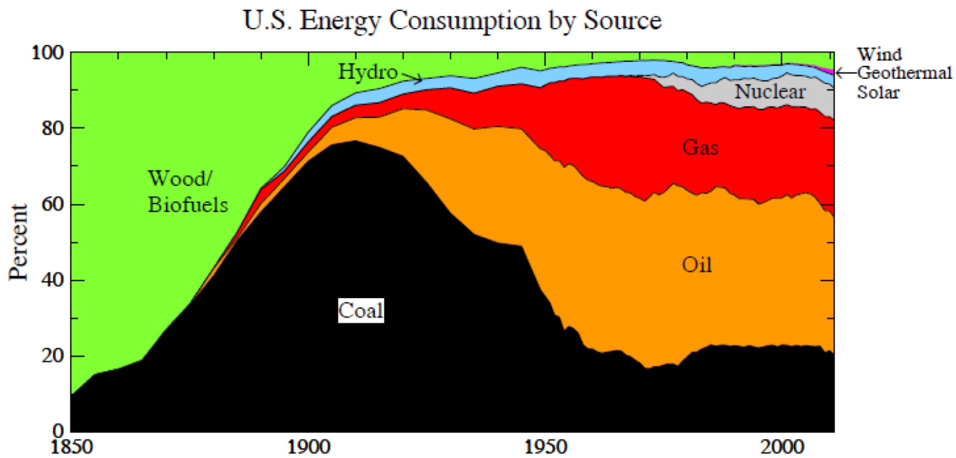

Figure 13. United States energy consumption [229].
doi:10.1371/journal.pone.0081648.g013

calculate that global emissions would have needed to decline 2.1%/year to limit cumulative fossil fuel emissions to 500 GtC. A start date of 2005 would have required a reduction of 3.5%/year for the same result.

The task faced today is more difficult. Emissions reduction of 6%/year and 100 GtC storage in the biosphere and soils are needed to get CO_2 back to 350 ppm, the approximate requirement for restoring the planet's energy balance and stabilizing climate this century. Such a pathway is exceedingly difficult to achieve, given the current widespread absence of policies to drive rapid movement to carbon-free energies and the lifetime of energy infrastructure in place.

Yet we suggest that a pathway is still conceivable that could restore planetary energy balance on the century time scale. That path requires policies that spur technology development and provide economic incentives for consumers and businesses such that social tipping points are reached where consumers move rapidly to energy conservation and low carbon energies. Moderate overshoot of required atmospheric CO_2 levels can possibly be counteracted via incentives for actions that more-or-less naturally sequester carbon. Developed countries, responsible for most of the excess CO_2 in the air, might finance extensive efforts in developing countries to sequester carbon in the soil and in forest regrowth on marginal lands as described above. Burning sustainably designed biofuels in power plants, with the CO_2 captured and sequestered, would also help draw down atmospheric CO_2. This pathway would need to be taken soon, as the magnitude of such carbon extractions is likely limited and thus not a solution to unfettered fossil fuel use.

The alternative pathway, which the world seems to be on now, is continued extraction of all fossil fuels, including development of unconventional fossil fuels such as tar sands, tar shale, hydrofracking to extract oil and gas, and exploitation of methane hydrates. If that path (with 2%/year growth) continues for 20 years and is then followed by 3%/year emission reduction from 2033 to 2150, we find that fossil fuel emissions in 2150 would total 1022 GtC. Extraction of the excess CO_2 from the air in this case would be very expensive and perhaps implausible, and warming of the ocean and resulting climate impacts would be practically irreversible.

Economic Implications: Need for a Carbon Fee

The implication is that the world must move rapidly to carbon-free energies and energy efficiency, leaving most remaining fossil fuels in the ground, if climate is to be kept close to the Holocene range and climate disasters averted. Is rapid change possible?

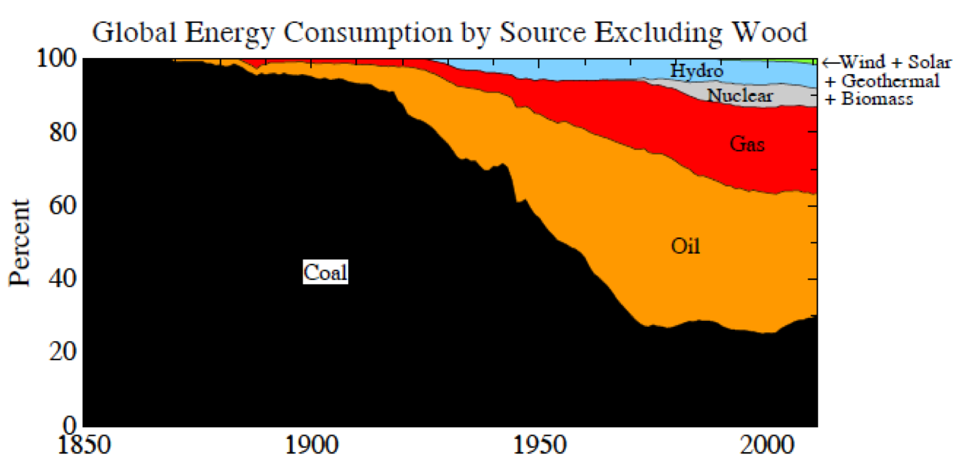

Figure 14. World energy consumption for indicated fuels, which excludes wood [4].
doi:10.1371/journal.pone.0081648.g014

The potential for rapid change can be shown by examples. A basic requirement for phasing down fossil fuel emissions is abundant carbon-free electricity, which is the most rapidly growing form of energy and also has the potential to provide energy for transportation and heating of buildings. In one decade (1977–1987), France increased its nuclear power production 15-fold, with the nuclear portion of its electricity increasing from 8% to 70% [231]. In one decade (2001–2011) Germany increased the non-hydroelectric renewable energy portion of its electricity from 4% to 19%, with fossil fuels decreasing from 63% to 61% (hydroelectric decreased from 4% to 3% and nuclear power decreased from 29% to 18%) [231].

Given the huge task of replacing fossil fuels, contributions are surely required from energy efficiency, renewable energies, and nuclear power, with the mix depending on local preferences. Renewable energy and nuclear power have been limited in part by technical challenges. Nuclear power faces persistent concerns about safety, nuclear waste, and potential weapons proliferation, despite past contributions to mortality prevention and climate change mitigation [232]. Most renewable energies tap diffuse intermittent sources often at a distance from the user population, thus requiring large-scale energy storage and transport. Developing technologies can ameliorate these issues, as discussed below. However, apparent cost is the constraint that prevents nuclear and renewable energies from fully supplanting fossil fuel electricity generation.

Transition to a post-fossil fuel world of clean energies will not occur as long as fossil fuels appear to the investor and consumer to be the cheapest energy. Fossil fuels are cheap only because they do not pay their costs to society and receive large direct and indirect subsidies [233]. Air and water pollution from fossil fuel extraction and use have high costs in human health, food production, and natural ecosystems, killing more than 1,000,000 people per year and affecting the health of billions of people [232,234], with costs borne by the public. Costs of climate change and ocean acidification, already substantial and expected to grow considerably [26,235], also are borne by the public, especially by young people and future generations.

Thus the essential underlying policy, albeit not sufficient, is for emissions of CO_2 to come with a price that allows these costs to be internalized within the economics of energy use. Because so much energy is used through expensive capital stock, the price should rise in a predictable way to enable people and businesses to efficiently adjust lifestyles and investments to minimize costs. Reasons for preference of a carbon fee or tax over cap-and-trade include the former's simplicity and relative ease of becoming global [236]. A near-global carbon tax might be achieved, e.g., via a bi-lateral agreement between China and the United States, the greatest emitters, with a border duty imposed on products from nations without a carbon tax, which would provide a strong incentive for other nations to impose an equivalent carbon tax. The suggestion of a carbon fee collected from fossil fuel companies with all revenues distributed to the public on a per capita basis [237] has received at least limited support [238].

Economic analyses indicate that a carbon price fully incorporating environmental and climate damage would be high [239]. The cost of climate change is uncertain to a factor of 10 or more and could be as high as ~$1000/tCO$_2$ [235,240]. While the imposition of such a high price on carbon emissions is outside the realm of short-term political feasibility, a price of that magnitude is not required to engender a large change in emissions trajectory.

An economic analysis indicates that a tax beginning at $15/tCO$_2$ and rising $10/tCO$_2$ each year would reduce emissions in the U.S. by 30% within 10 years [241]. Such a reduction is more than 10 times as great as the carbon content of tar sands oil carried by the proposed Keystone XL pipeline (830,000 barrels/day) [242]. Reduced oil demand would be nearly six times the pipeline capacity [241], thus the carbon fee is far more effective than the proposed pipeline.

A rising carbon fee is the *sine qua non* for fossil fuel phase out, but not enough by itself. Investment is needed in RD&D (research, development and demonstration) to help renewable energies and nuclear power overcome obstacles limiting their contributions. Intermittency of solar and wind power can be alleviated with advances in energy storage, low-loss smart electric grids, and electrical vehicles interacting with the grid. Most of today's nuclear power plants have half-century-old technology with light-water reactors [243] utilizing less than 1% of the energy in the nuclear fuel and leaving unused fuel as long-lived nuclear "waste" requiring sequestration for millennia. Modern light-water reactors can employ convective cooling to eliminate the need for external cooling in the event of an anomaly such as an earthquake. However, the long-term future of nuclear power will employ "fast" reactors, which utilize ~99% of the nuclear fuel and can "burn" nuclear waste and excess weapons material [243]. It should be possible to reduce the cost of nuclear power via modular standard reactor design, but governments need to provide a regulatory environment that supports timely construction of approved designs. RD&D on carbon capture and storage (CCS) technology is needed, especially given our conclusion that the current atmospheric CO_2 level is already in the dangerous zone, but continuing issues with CCS technology [7,244] make it inappropriate to construct fossil fuel power plants with a promise of future retrofit for carbon capture. Governments should support energy planning for housing and transportation, energy and carbon efficiency requirements for buildings, vehicles and other manufactured products, and climate mitigation and adaptation in undeveloped countries.

Economic efficiency would be improved by a rising carbon fee. Energy efficiency and alternative low-carbon and no-carbon energies should be allowed to compete on an equal footing, without subsidies, and the public and business community should be made aware that the fee will continually rise. The fee for unconventional fossil fuels, such as oil from tar sands and gas from hydrofracking, should include carbon released in mining and refining processes, e.g., methane leakage in hydrofracking [245–249]. If the carbon fee rises continually and predictably, the resulting energy transformations should generate many jobs, a welcome benefit for nations still suffering from long-standing economic recession. Economic modeling shows that about 60% of the public, especially low-income people, would receive more money via a per capita 100% dispersal of the collected fee than they would pay because of increased prices [241].

Fairness: Intergenerational Justice and Human Rights

Relevant fundamentals of climate science are clear. The physical climate system has great inertia, which is due especially to the thermal inertia of the ocean, the time required for ice sheets to respond to global warming, and the longevity of fossil fuel CO_2 in the surface carbon reservoirs (atmosphere, ocean, and biosphere). This inertia implies that there is additional climate change "in the pipeline" even without further change of atmospheric composition. Climate system inertia also means that, if large-scale climate change is allowed to occur, it will be exceedingly long-lived, lasting for many centuries.

One implication is the likelihood of intergenerational effects, with young people and future generations inheriting a situation in which grave consequences are assured, practically out of their control, but not of their doing. The possibility of such intergenerational injustice is not remote – it is at our doorstep now. We have a planetary climate crisis that requires urgent change to our energy and carbon pathway to avoid dangerous consequences for young people and other life on Earth.

Yet governments and industry are rushing into expanded use of fossil fuels, including unconventional fossil fuels such as tar sands, tar shale, shale gas extracted by hydrofracking, and methane hydrates. How can this course be unfolding despite knowledge of climate consequences and evidence that a rising carbon price would be economically efficient and reduce demand for fossil fuels? A case has been made that the absence of effective governmental leadership is related to the effect of special interests on policy, as well as to public relations efforts by organizations that profit from the public's addiction to fossil fuels [237,250].

The judicial branch of governments may be less subject to pressures from special financial interests than the executive and legislative branches, and the courts are expected to protect the rights of all people, including the less powerful. The concept that the atmosphere is a public trust [251], that today's adults must deliver to their children and future generations an atmosphere as beneficial as the one they received, is the basis for a lawsuit [252] in which it is argued that the U.S. government is obligated to protect the atmosphere from harmful greenhouse gases.

Independent of this specific lawsuit, we suggest that intergenerational justice in this matter derives from fundamental rights of equality and justice. The Universal Declaration of Human Rights [253] declares "All are equal before the law and are entitled without any discrimination to equal protection of the law." Further, to consider a specific example, the United States Constitution provides all citizens "equal protection of the laws" and states that no person can be deprived of "life, liberty or property without due process of law". These fundamental rights are a basis for young people to expect fairness and justice in a matter as essential as the condition of the planet they will inhabit. We do not prescribe the legal arguments by which these rights can be achieved, but we maintain that failure of governments to effectively address climate change infringes on fundamental rights of young people.

Ultimately, however, human-made climate change is more a matter of morality than a legal issue. Broad public support is probably needed to achieve the changes needed to phase out fossil fuel emissions. As with the issue of slavery and civil rights, public recognition of the moral dimensions of human-made climate change may be needed to stir the public's conscience to the point of action.

A scenario is conceivable in which growing evidence of climate change and recognition of implications for young people lead to massive public support for action. Influential industry leaders, aware of the moral issue, may join the campaign to phase out emissions, with more business leaders becoming supportive as they recognize the merits of a rising price on carbon. Given the relative ease with which a flat carbon price can be made international [236], a rapid global emissions phasedown is feasible. As fossil fuels are made to pay their costs to society, energy efficiency and clean energies may reach tipping points and begin to be rapidly adopted.

Our analysis shows that a set of actions exists with a good chance of averting "dangerous" climate change, if the actions begin now. However, we also show that time is running out. Unless a human "tipping point" is reached soon, with implementation of effective policy actions, large irreversible climate changes will become unavoidable. Our parent's generation did not know that their energy use would harm future generations and other life on the planet. If we do not change our course, we can only pretend that we did not know.

Discussion

We conclude that an appropriate target is to keep global temperature within or close to the temperature range in the Holocene, the interglacial period in which civilization developed. With warming of 0.8°C in the past century, Earth is just emerging from that range, implying that we need to restore the planet's energy balance and curb further warming. A limit of approximately 500 GtC on cumulative fossil fuel emissions, accompanied by a net storage of 100 GtC in the biosphere and soil, could keep global temperature close to the Holocene range, assuming that the net future forcing change from other factors is small. The longevity of global warming (Fig. 9) and the implausibility of removing the warming if it is once allowed to penetrate the deep ocean emphasize the urgency of slowing emissions so as to stay close to the 500 GtC target.

Fossil fuel emissions of 1000 GtC, sometimes associated with a 2°C global warming target, would be expected to cause large climate change with disastrous consequences. The eventual warming from 1000 GtC fossil fuel emissions likely would reach well over 2°C, for several reasons. With such emissions and temperature tendency, other trace greenhouse gases including methane and nitrous oxide would be expected to increase, adding to the effect of CO_2. The global warming and shifting climate zones would make it less likely that a substantial increase in forest and soil carbon could be achieved. Paleoclimate data indicate that slow feedbacks would substantially amplify the 2°C global warming. It is clear that pushing global climate far outside the Holocene range is inherently dangerous and foolhardy.

The fifth IPCC assessment Summary for Policymakers [14] concludes that to achieve a 50% chance of keeping global warming below 2°C equivalent CO_2 emissions should not exceed 1210 GtC, and after accounting for non-CO_2 climate forcings this limit on CO_2 emissions becomes 840 GtC. The existing drafts of the fifth IPCC assessment are not yet approved for comparison and citation, but the IPCC assessment is consistent with studies of Meinshausen et al. [254] and Allen et al. [13], hereafter M2009 and A2009, with which we can make comparisons. We will also compare our conclusions with those of McKibben [255]. M2009 and A2009 appear together in the same journal with the two lead authors on each paper being co-authors on the other paper. McKibben [255], published in a popular magazine, uses quantitative results of M2009 to conclude that most remaining fossil fuel reserves must be left in the ground, if global warming this century is to be kept below 2°C. McKibben [255] has been very successful in drawing public attention to the urgency of rapidly phasing down fossil fuel emissions.

M2009 use a simplified carbon cycle and climate model to make a large ensemble of simulations in which principal uncertainties in the carbon cycle, radiative forcings, and climate response are allowed to vary, thus yielding a probability distribution for global warming as a function of time throughout the 21st century. M2009 use this distribution to infer a limit on total (fossil fuel+net land use) carbon emissions in the period 2000–2049 if global warming in the 21st century is to be kept below 2°C at some specified probability. For example, they conclude that the limit on total 2000–2049 carbon emissions is 1440 $GtCO_2$ (393 GtC) to achieve a 50% chance that 21st century global warming will not exceed 2°C.

A2009 also use a large ensemble of model runs, varying uncertain parameters, and conclude that total (fossil fuel+net land use) carbon emissions of 1000 GtC would most likely yield a peak

CO_2-induced warming of 2°C, with 90% confidence that the peak warming would be in the range 1.3–3.9°C. They note that their results are consistent with those of M2009, as the A2009 scenarios that yield 2°C warming have 400–500 GtC emissions during 2000–2049; M2009 find 393 GtC emissions for 2°C warming, but M2009 included a net warming effect of non-CO_2 forcings, while A2009 neglected non-CO_2 forcings.

McKibben [255] uses results of M2009 to infer allowable fossil fuel emissions up to 2050 if there is to be an 80% chance that maximum warming in the 21st century will not exceed 2°C above the pre-industrial level. M2009 conclude that staying under this 2°C limit with 80% probability requires that 2000–2049 emissions must be limited to 656 $GtCO_2$ (179 GtC) for 2007–2049. McKibben [255] used this M2009 result to determine a remaining carbon budget (at a time not specified exactly) of 565 $GtCO_2$ (154 GtC) if warming is to stay under 2°C. Let us update this analysis to the present: fossil fuel emissions in 2007–2012 were 51 GtC [5], so, assuming no net emissions from land use in these few years, the M2009 study implies that the remaining budget at the beginning of 2013 was 128 GtC.

Thus, coincidentally, the McKibben [255] approach via M2009 yields almost exactly the same remaining carbon budget (128 GtC) as our analysis (130 GtC). However, our budget is that required to limit warming to about 1°C (there is a temporary maximum during this century at about 1.1–1.2°C, Fig. 9), while McKibben [255] is allowing global warming to reach 2°C, which we have concluded would be a disaster scenario! This apparently vast difference arises from three major factors.

First, we assumed that reforestation and improved agricultural and forestry practices can suck up the net land use carbon of the past. We estimate net land use emissions as 100 GtC, while M2009 have land use emissions almost twice that large (~180 GtC). We argue elsewhere (see section 14 in Supporting Information of [54]) that the commonly employed net land use estimates [256] are about a factor of two larger than the net land use carbon that is most consistent with observed CO_2 history. However, we need not resolve that long-standing controversy here. The point is that, to make the M2009 study equivalent to ours, negative land use emissions must be included in the 21st century equal to earlier positive land use emissions.

Second, we have assumed that future net change of non-CO_2 forcings will be zero, while M2009 have included significant non-CO_2 forcings. In recent years non-CO_2 GHGs have provided about 20% of the increase of total GHG climate forcing.

Third, our calculations are for a single fast-feedback equilibrium climate sensitivity, 3°C for doubled CO_2, which we infer from paleoclimate data. M2009 use a range of climate sensitivities to compute a probability distribution function for expected warming, and then McKibben [255] selects the carbon emission limit that keeps 80% of the probability distribution below 2°C.

The third factor is a matter of methodology, but one to be borne in mind. Regarding the first two factors, it may be argued that our scenario is optimistic. That is true, but both goals, extracting 100 GtC from the atmosphere via improved forestry and agricultural practices (with possibly some assistance from CCS technology) and limiting additional net change of non-CO_2 forcings to zero, are feasible and probably much easier than the principal task of limiting additional fossil fuel emissions to 130 GtC.

We noted above that reforestation and improving agricultural and forestry practices that store more carbon in the soil make sense for other reasons. Also that task is made easier by the excess CO_2 in the air today, which causes vegetation to take up CO_2 more efficiently. Indeed, this may be the reason that net land use emissions seem to be less than is often assumed.

As for the non-CO_2 forcings, it is noteworthy that greenhouse gases controlled by the Montreal Protocol are now decreasing, and recent agreement has been achieved to use the Montreal Protocol to phase out production of some additional greenhouse gases even though those gases do not affect the ozone layer. The most important non-CO_2 forcing is methane, whose increases in turn cause tropospheric ozone and stratospheric water vapor to increase. Fossil fuel use is probably the largest source of methane [1], so if fossil fuel use begins to be phased down, there is good basis to anticipate that all three of these greenhouse gases could decrease, because of the approximate 10-year lifetime of methane.

As for fossil fuel CO_2 emissions, considering the large, long-lived fossil fuel infrastructure in place, the science is telling us that policy should be set to reduce emissions as rapidly as possible. The most fundamental implication is the need for an across-the-board rising fee on fossil fuel emissions in order to allow true free market competition from non-fossil energy sources. We note that biospheric storage should not be allowed to offset further fossil fuel emissions. Most fossil fuel carbon will remain in the climate system more than 100,000 years, so it is essential to limit the emission of fossil fuel carbon. It will be necessary to have incentives to restore biospheric carbon, but these must be accompanied by decreased fossil fuel emissions.

A crucial point to note is that the three tasks [limiting fossil fuel CO_2 emissions, limiting (and reversing) land use emissions, limiting (and reversing) growth of non-CO_2 forcings] are interactive and reinforcing. In mathematical terms, the problem is non-linear. As one of these climate forcings increases, it increases the others. The good news is that, as one of them decreases, it tends to decrease the others. In order to bestow upon future generations a planet like the one we received, we need to win on all three counts, and by far the most important is rapid phasedown of fossil fuel emissions.

It is distressing that, despite the clarity and imminence of the danger of continued high fossil fuel emissions, governments continue to allow and even encourage pursuit of ever more fossil fuels. Recognition of this reality and perceptions of what is "politically feasible" may partially account for acceptance of targets for global warming and carbon emissions that are well into the range of "dangerous human-made interference" with climate. Although there is merit in simply chronicling what is happening, there is still opportunity for humanity to exercise free will. Thus our objective is to define what the science indicates is needed, not to assess political feasibility. Further, it is not obvious to us that there are physical or economic limitations that prohibit fossil fuel emission targets far lower than 1000 GtC, even targets closer to 500 GtC. Indeed, we suggest that rapid transition off fossil fuels would have numerous near-term and long-term social benefits, including improved human health and outstanding potential for job creation.

A world summit on climate change will be held at United Nations Headquarters in September 2014 as a preliminary to negotiation of a new climate treaty in Paris in late 2015. If this treaty is analogous to the 1997 Kyoto Protocol [257], based on national targets for emission reductions and cap-and-trade-with-offsets emissions trading mechanisms, climate deterioration and gross intergenerational injustice will be practically guaranteed. The palpable danger that such an approach is conceivable is suggested by examination of proposed climate policies of even the most forward-looking of nations. Norway, which along with the other Scandinavian countries has been among the most ambitious and successful of all nations in reducing its emissions, nevertheless approves expanded oil drilling in the Arctic and development of tar sands as a majority owner of Statoil [258–259]. Emissions foreseen by the Energy Perspectives of Statoil [259], if they occur, would approach or exceed 1000 GtC and cause dramatic climate change that would run out of control of future generations. If, in contrast, leading nations agree in 2015 to have internal rising fees on carbon with border duties on products from nations without a carbon fee, a foundation would be established for phaseover to carbon free energies and stable climate.

Supporting Information

Table S1
(ODS)

Table S2
(ODS)

Table S3
(ODS)

Text S1
(DOC)

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Author Contributions

Conceived and designed the experiments: JH PK MS. Performed the experiments: MS PK. Wrote the paper: JH. Wrote the first draft: JH. All authors made numerous critiques and suggested specific wording and references: JH PK MS VM-D FA DJB PJH OHG SLH CP JR EJR JS PS KS LVS KvS JCZ. Especially: PK MS VM-D.

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Reservoirs are underappreciated source of greenhouse gases

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By Eric Sorensen, WSU science writer

VANCOUVER, Wash. – Washington State University researchers say the world's reservoirs are an underappreciated source of greenhouse gases, producing the equivalent of roughly 1 gigaton of carbon dioxide a year, or 1.3 percent of all greenhouse gases produced by humans.

That's more greenhouse gas production than all of Canada.

Writing in next week's journal BioScience, the WSU researchers say reservoirs are a particularly important source of methane, a greenhouse gas that is 34 times more potent than carbon dioxide over the course of a century. Reservoir methane production is comparable to rice paddies or biomass burning, both of which are included in emission estimates of the Intergovernmental Panel on Climate Change, the leading international authority on the subject.

John Harrison, co-author and associate professor in the WSU Vancouver School of the Environment, last month attended a meeting in Minsk, Belarus, to discuss including reservoir emissions in a planned 2019 IPCC update of how countries report their greenhouse gas inventories.

Methane accounts for 80 percent

"We had a sense that methane might be pretty important but we were surprised that it was as important as it was," said Bridget Deemer, WSU research associate and lead author. "It's contributing right around 80 percent of the total global warming impact of all those gases from reservoirs. It's a pretty important piece of the budget."

The BioScience analysis, which drew on scores of other studies, is the largest and most comprehensive look to date at the link between reservoirs and greenhouse gases, Harrison said.

"Not only does it incorporate the largest number of studies," he said. "It also looks at more types of greenhouse gases than past studies."

Acre per acre, reservoirs emit 25 percent more methane than previously thought, he said.

The researchers acknowledge that reservoirs provide important services like electrical power, flood control, navigation and water. But reservoirs have also altered the dynamics of river ecosystems, impacting fish and other life forms. Only lately have researchers started to look at reservoirs' impact on greenhouse gases.

"While reservoirs are often thought of as 'green' or carbon neutral sources of energy, a growing body of work has documented their role as greenhouse gas sources," Deemer, Harrison and their colleagues write.

Gases from decomposing organic matter

Unlike natural water bodies, reservoirs tend to have flooded large amounts of organic matter that produce carbon dioxide, methane and nitrous oxide as they decompose. Reservoirs also receive a lot of organic matter and "nutrients" like nitrogen and phosphorous from upstream rivers, which can further stimulate greenhouse gas production

In 2000, BioScience published one of the first papers to assert that reservoir greenhouse gases contribute substantially to global warming. Since then, there has been a nine-fold increase in studies of reservoirs and greenhouse gases. Where earlier studies tended to be confined to reservoirs behind power stations, the newer studies also looked at reservoirs used for flood control, water storage, navigation and irrigation.

The WSU researchers are the first to consider methane bubbling in models of reservoir greenhouse gas emissions. Also, while previous papers have found that young, tropical reservoirs emit more methane than older, more northern systems, this study finds that the total global warming effect of a reservoir is best predicted by how biologically productive it is, with more algae and nutrient rich systems producing more methane.

The authors also report higher per-area rates of methane emission from reservoirs than have been reported previously. This means that acre-for-acre the net effect of new reservoirs on atmospheric greenhouse gases will be greater than previously thought. Reservoir construction around the globe is expected to proceed rapidly in coming decades.

Largest study of reservoir greenhouse gas emissions

"There's been a growing sense in the literature that methane bubbles are a really important component of the total emissions from lake and reservoir ecosystems," said Deemer. "This study revisited the literature to try and synthesize what we know about the magnitude and control on methane emissions and other greenhouse gases—carbon dioxide and nitrous oxide."

The result is that, in addition to being the largest study of reservoir greenhouse gas emissions to date, it is the first to comprehensively look at the flow of all three major greenhouse gases—carbon dioxide, methane and nitrous oxide—from reservoirs to the atmosphere.

The work is in keeping with WSU's Grand Challenges, a suite of research initiatives aimed at large societal issues. It is particularly relevant to the challenge of sustainable resources and its themes of supplying food, energy and water for future generations.

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