2010 Blue Planet Prize
Commemorative Lectures

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THE ASAHI GLASS FOUNDATION

CONTENTS

Dr. James Hansen (USA)

Director at Goddard Institute for Space Studies (NASA)
Adjunct professor in the Department of Earth and Environmental Sciences at Columbia University

Selection rationale: Having predicted global warming in the early stage and warned that it would very probably cause destructive results for life on Earth, he called on the governments and the public to take immediate action to reduce and mitigate the impact of climate change.

Education and Academic and Professional Activities

1941	Born in USA
1963	Receives a bachelor's degree in physics and mathematics at the University of Iowa
1965, 1967	Receives a master's degree in astronomy and a doctorate in physics at the University of Iowa
1967-1969	A researcher at Goddard Institute for Space Studies (New York)
1969	Post-doctoral fellow at Leiden Observatory (Netherlands)
1969-1972	Researcher at Columbia University (New York)
1972-1981	Manager of the planetary atmospheres program at Goddard Institute for Space Studies
1978-1985	Adjunct professor in the Department of Earth Sciences at Columbia University
1981-present	Director at Goddard Institute for Space Studies
1985-present	Adjunct professor in the Department of Earth and Environmental Sciences at Columbia University

Major Awards Received

1996	Elected to United States National Academy of Sciences
2001	John Heinz Environment Award
	Roger Revelle Medal, American Geophysical Union
2006	Duke of Edinburgh Conservation Medal, World Wildlife Fund (WWF)
2007	Laureate, Dan David Prize for Outstanding Achievements & Impacts in Quest for Energy
	Leo Szilard Award, American Physical Society for Outstanding Promotion & Use of Physics for the Benefit of Society
	Haagen-Smit Clean Air Award
	American Association for the Advancement of Science Award for Scientific Freedom and Responsibility
2009	Carl-Gustaf Rossby Research Medal, highest award of American Meteorological Society
2010	Sophie Prize

Based on the concept of radiative forcing to indicate the flow of radiation energy in the atmosphere, Dr. Hansen et al. succeeded in developing a practical climate model that was proven by tests such as the Pinatubuo volcanic eruption – they predicted global cooling to follow, which proved quite accurate – there are other verifications, and pioneered understanding and forecasting of the climate system. At a time when there was a noticeable temperature decline because of the impact of the sun and volcanic activity, Dr. Hansen predicted global warming in the future based on the climate model. In 1988, he got more attention with strong statements at an appropriate time to testify before committees and subcommittees in the US Senate and House of Representatives and provided the public with an early alert to the dangers of global warming and to call for actions. Later he claimed that the climate had a "tipping point," and warned that an average temperature increase of even a few degrees would very probably cause irreversible and unrecoverable climate change and produce destructive results for life on Earth. Dr. Hansen called on the governments and the public to take immediate action to reduce and mitigate the impact of climate change. He has consistently emphasized the need for unprecedented international cooperation and significantly contributed to enlightening the whole world about global environment issues.

From astronomy to climate science

Study of planetary atmosphere

Dr. Hansen was born on a farm, located in Charter Oak township, Iowa in 1941. Attracted to the renowned space science program of Professor James Van Allen of the University of Iowa, he received a master's degree in astronomy and a doctorate in physics at the university. While attending the University of Iowa, he came to Japan and did researches on astrophysics and astronomy at the University of Kyoto and the University of Tokyo, respectively. Professor Sueo Ueno of Univ. of Kyoto kindly introduced Dr. Hansen to his methods of computation called "invariant imbedding", which is one of the techniques Dr. Hansen used for radiative transfer in planetary atmospheres.

In 1967, he analyzed the data on Venusian temperature and published a thesis arguing that the high temperature of Venus was attributable to a trap of thermal energy caused by aerosol in the atmosphere. In 1974 and 1975, he studied the composition of clouds in the Venusian atmosphere, which completely veil the planet so that its surface cannot be seen. He reported that the clouds consisted of very small spherical droplets of nearly uniform size – he also was able to measure the index of refraction of these droplets and how this index changed from ultraviolet to green to red and infrared wavelengths – this precise information was used by others to conclude that the hazy veil shrouding Venus must be sulfuric acid. The Pioneer Venus spacecraft launched in 1978 confirmed the properties that Dr. Hansen had inferred from telescopic observations and confirmed that the haze was sulfuric acid. The validity of the finding was proven by the Pioneer Venus Orbiter in 1978. In 1981, Dr. Hansen reported that the clouds consisted of sulfuric acid airborne droplets and sulfur dioxide.

Other researchers reported that Venus had been rich in water until several billion years before and that the water had disappeared from the surface of the planet due to the runaway greenhouse effect that subsequently occurred.[1] Later, Dr. Hansen warned that an occurrence of this kind of runaways warming could expose Earth to a harsh environment like it did to Venus, through the evaporation of water.[2]

Then Dr. Hansen shifted the focus of his study to climate change that is caused by human activities which change the composition of Earth's atmosphere. He utilized NASA's satellite observation data in studying the thermal radiation of Earth's atmosphere, which led to the development of a global-scale atmospheric circulation model and significantly contributed to a detailed understanding, analyses and predictions of climate change that included the impact of human activities.

Study of the Earth's climate

In 1987, Dr. Hansen et al. summarized and published the data on the atmospheric temperature of Earth mainly during the period between 1880 and 1985 obtained from global weather stations. Accurate data on atmospheric temperature from the last 100 years showed a rise of 0.5 - 0.7 degrees in the average temperature. The recorded figures of average temperature increase, updated in 2006, reached 0.8 degrees/100 years, showing that the tendency toward global warming was an undeniable fact and was not merely a result of urbanization.

In a thesis published with Dr. Menon et al., Dr. Hansen argued that there is the existence of atmospheric black carbon effects in the climate of some local regions. He showed that black carbon in the atmosphere brought convection and rain by heating the atmosphere and would ultimately lower temperatures over large areas by reducing the amount of sunlight reaching the ground. As an example, he explained a climatic abnormality observed in northern China in 1988. Then Dr. Hansen joined Dr. Makiko Sato in conducting a study using the solar photometer of AERONET (AErosol RObotic NET work) and showed that the impact of black carbon doubled the value that would normally be estimated from it. Black carbon in the atmosphere rapidly increased in the 1880s when the Industrial Revolution was at its peak. The increase slowed down from the 1900s to the 1950s and leveled off. Even at present, the emissions of black carbon are increasing in China and India, which are in the midst of their rapid economic growth.

Impact of human activities on climate change

In 2003, Dr. Hansen published an essay titled *"Can We Defuse the Global Warming Time Bomb?"* He warned that the climate change resultant from human activities has currently overcome natural climate change and, if this persists for extended periods, could grow to an enormous level causing great disasters. He also said that actions to prevent or mitigate global warming and other undesirable climate change phenomena need to be taken immediately, and that unprecedented kinds of international cooperation would be called for. He also stressed that such mitigating actions would be feasible and would benefit the health of humankind as well as agriculture and the environment.

In 2006, Dr. Hansen et al. suggested that the average temperature of Earth should be regarded as a yardstick of the degree of impact of human activities on the Earth's atmospheric system. He emphasized that the rise of the average temperature was inevitably accompanied by "a rise in the sea level" and "extinction of species" and that an increase in the average temperature of even one degree would produce highly destructive results for life on Earth. According to him, a CO_2 level of 450ppm or greater in the atmosphere would pose a great deal of danger and powerful measures to reduce CO_2 and other greenhouse gases are important and must be taken immediately.

Advocating conservation of the global environment

In 1988, Dr. Hansen published a thesis on climate predictions using a general atmospheric circulation model based on some scenarios of greenhouse gas emissions. He concluded that the global warming caused by human activities would grow to a level well above the level of natural climate variability within the next few decades. In the same year, Dr. Hansen testified before committees and subcommittees in the U.S. Senate and House of Representatives and provided the public with an extensive alert to the dangers of global warming.

In 2007, he used his knowledge of paleoclimatology to show that the sea level of 35 million years ago (when the average temperature of Earth was two or three degrees higher than today) was 25 meters higher than the current level and that the IPCC's estimate, 59 centimeters, was far from correct. In 2008, he gave a lecture and explained the definition of a tipping point, a threshold of climate change that humankind must not exceed, as 1) a tipping level: the level at which a large climate change occurs even when greenhouse gases do not increase any further; and 2) a point of no return: the point at which the climate system causes an uncontrollable and irreversible change on the climate. According to paleoclimatology, ice in the polar areas would dissolve suddenly instead of dissolving gradually. This can be interpreted as an example of a tipping point. Dr. Hansen uses multiple lines of evidence to conclude that the world has already reached a dangerous level of atmospheric greenhouse gases, but he admits that it is difficult to determine how long the world can be in the dangerous zone before the effects become large and irreversible. However, he argues further that if emissions continue at current or increased levels for a few decades large climate changes and impacts will proceed out of humanity's control.

Dr. Hansen recommends that all nations should determine their responsibilities for greenhouse gas emissions based on a historical viewpoint, more specifically, the cumulative amount of their CO_2 emissions. According to this yardstick, United Kingdom would be the largest cause of greenhouse gas emissions followed by the United States and Germany. He urges nations to base their actions on the extent of their responsibilities.

Last year, Dr. Hansen urged the US government to set an example and lead the world in taking actions against climate change, because humankind should no longer postpone the implementation of anti-global warming measures. To ensure the next generations a better future, Dr. Hansen continues to explain to government officials and the public about the danger of global warming and to advocate early actions for reduction of greenhouse gases with the aim of conserving the global environment.

Notes

1: Kasting J.F. (1988) "Runaway and moist greenhouse atmospheres and the evolution of earth and Venus" Icarus 74 (3): 472–494.

2: Climate Threat to the Planet: Implication for Energy Policy and Intergenerational Justice Jim Hansen December 17, 2008 Lecture at AGU

Human-Made Climate Change: A Moral, Political and Legal Issue

Dr. James Hansen

Summary of the Situation

#1 Human-made climate change is a moral issue. It pits the rich and the powerful against the young and the unborn, against the defenseless and against nature.

Climate change is a political issue. But politics fails when there is a revolving door between government and the fossil fuel-industrial complex.

Climate change is a legal issue. The judiciary provides the possibility of holding our governments accountable for their duty to protect the public interest.

#2 There is a huge gap between what is understood about global warming, by the relevant scientific community, and what is known about global warming by the people who need to know, the public.

It is difficult for the public to recognize that we have a crisis, because human-made global warming, so far, is small compared to day-to-day weather fluctuations. Yet the fact is: we have an emergency. Because of the great inertia of the ocean, which is 4 kilometers deep, and the ice sheets, which are 2 to 3 kilometers thick, the climate system responds slowly to climate forcings such as increasing greenhouse gases. But this inertia is not our friend, because it increases the danger that we may pass tipping points, beyond which the dynamics of the climate system takes over and rapid changes occur out of humanity's control.

The bad news is that atmospheric carbon dioxide (CO_2) has already reached a dangerous level, having increased from 280 parts per million (ppm) 200 years ago to 389 ppm today. The good news is that it is still possible to get CO_2 back below 350 ppm, if we act promptly, and there would be many benefits of taking the actions that are needed.

#3 The great ice sheets on Greenland and Antarctica provide examples of tipping points, especially the West Antarctic ice sheet, which sits on bedrock below sea level. If an ice sheet is weakened to the point that it begins to collapse, the dynamics of the process takes over. It will be out of our control – we cannot tie a rope around an ice sheet that is two kilometers thick.

Extermination of species is another non-linear problem that can accelerate, because of the interdependencies among species. Multiple stresses may cause enough extinctions that ecosystems collapse.

Methane hydrates are essentially frozen methane. If they begin to disintegrate rapidly, it could become a self-sustaining process.

These tipping points all have occurred during Earth's history in conjunction with warming climates. Following mass extinctions new species evolved, but it required hundreds of thousands of years. We will leave a much more desolate planet for future generations, if we destroy many species.

#4 Climate inertia and tipping points give rise to potential intergenerational injustice. Today's adults enjoy the benefits of fossil fuel use, but the impacts will be borne by young people and future generations. Our parents did not know that their actions would affect future generations. We do not have that excuse. We can only feign ignorance. It is called denial.

I showed this photo of our first grandchild in 2000, because newspapers had called me the grandfather of global warming. It was amusing to show that I really was a grandfather.

After I testified to Congress in the 1980s I had decided to stick to research and leave public communication to others. But by 2004 we had two grandchildren and the gap between what was understood about the science and what was known by the public had become huge. I decided to give one carefully prepared public talk in 2004.

#5 The talk was titled "Dangerous anthropogenic interference: a discussion of humanity's Faustian climate bargain and the payments coming due." I began with this chart comparing Mars, Earth and Venus. Mars has a thin atmosphere of carbon dioxide, Earth an intermediate amount, and Venus has a very thick carbon dioxide atmosphere. The greenhouse effect of carbon dioxide – the fact that it allows sunlight to penetrate to the planetary surface, but partially traps the planet's infrared (heat) radiation – causes each planet to be warmer than it would otherwise be, given the amount of sunlight that it absorbs – Mars by a few degrees, Earth by a few tens of degrees, and Venus by several hundred degrees.

Mars is too cold – its water is all frozen. Venus is too hot – the water has boiled into the atmosphere. Earth is just right for life to exist.

#6 The habitable zone around a star is the zone where liquid water can exist on a planet. Our sun is an ordinary star, "burning" hydrogen in its core, producing helium by nuclear fusion, slowly getting brighter. When the solar system was young the sun was 30 percent dimmer than today and the habitable zone was closer to the sun. Venus was cool enough to have an ocean. Earth was near the cold limit of the habitable zone. On several occasions Earth froze all the way to the equator. The most recent "snowball Earth" occurred about 700 million years ago.

As the sun brightened, Venus experienced a runaway greenhouse effect. The ocean evaporated, boiling into the atmosphere. Carbon dioxide baked from the Venus crust into the atmosphere. There is no going-back. Venus is permanently outside the habitable zone, locked forever in a hellish greenhouse with a surface hot enough to melt lead.

Earth is now near the middle of the habitable zone. Earth can never freeze over again. The sun is now too bright and humans have added greenhouse gases to the atmosphere. A runaway greenhouse effect will not occur naturally on Earth for several billion years. But if we burn all fossil fuels, including tar sands and oil shale, it is conceivable that we will hasten a runaway greenhouse effect.

How will climate change this century? It depends. It depends mainly on how much carbon dioxide humans put into the atmosphere.

#7 Our understanding of climate change is based most of all on Earth's history – how the climate responded in the past to changing boundary conditions such as atmospheric composition surface properties. Ongoing global observations are also valuable, showing how climate is responding to rapid changes of atmospheric composition. Climate models and theory are helpful in interpreting what is happening and they are needed to predict future changes.

#8 Why should we be concerned about human-made climate change? There have been huge climate changes in the past. Is today's climate the best one? These are reasonable questions. Indeed, they were statements made on National Public Radio in 2008 by my then boss's, boss's, boss's boss, the NASA Administrator. Earth's climate history helps answer such questions.

#9 This is the deep ocean temperature over the past 65 million years. 50 million years ago Earth was so warm that there were alligators in Alaska – the Arctic was tropical-like. There were no ice sheets and sea level was about 75 meters (250 feet) higher than today. Earth cooled over the past 50 million years. About 34 million years ago it became cool enough for an ice sheet to form on Antarctica. What caused the great warmth in the first half of this Cenozoic Era, and why did Earth then become cooler?

#10 The climate change was due mainly to change of atmospheric carbon dioxide (CO_2). Climate forcings, perturbations of the planet's energy balance, must be due to changes of the energy coming into the planet, changes within the atmosphere, or changes on the surface. The sun's luminosity increased 0.4 percent over this era, which is a forcing of 1 watt per square meter. The continents at the beginning of the Cenozoic were already close to their present latitudes, so the surface forcing was only about 1 watt. But atmospheric CO_2 varied from as little as 170 ppm to more than 1000 ppm, a forcing of more than 10 watts per square meter.

The amount of CO_2 naturally in the atmosphere-ocean system depends on the balance between the source and sink of CO_2. The balance changes over time, depending mainly on continental drift. The source of CO_2 is volcanic eruptions, which occur at moving continents subduct ocean floor. The metamorphosis of carbonates on the ocean floor into denser rocks, due to high pressure and temperature as the continent rides over the ocean floor, releases CO_2 via volcanoes. The main sink of atmospheric CO_2 is the weathering process as sediments are carried by rivers to the ocean and deposited as carbonates on the ocean floor.

Between 60 and 50 million years ago atmospheric CO_2 increased rapidly because India was moving at high speed, about 20 centimeters per year, through the Tethys (Indian) Ocean, which had long been the depocenter for major rivers and thus had a carbonate-rich ocean floor. When India crashed into Asia, pushing up the Himalayas and Tibetan Plateau, this source of CO_2 diminished and the weathering sink increased. So atmospheric CO_2 decreased and the planet cooled over the past 50 million years.

#11 The lesson from the Cenozoic is that the amount of CO_2 in the atmosphere-ocean system changes naturally via exchange with the Earth's crust. The imbalance between the source and sink of CO_2 yields a change of atmospheric CO_2 of the order of 100 ppm in one million years, or 1 ten-thousandths of a ppm per year. Humans are now increasing atmospheric CO_2 by about 2 ppm per year, 10,000 times faster than the natural geological change.

The Cenozoic also allows us to estimate that an ice sheet began to form on Antarctica when CO_2 had declined to about 450 ppm. Some scientists estimate a higher amount of CO_2 at the transition. But it is clear that burning all the fossil fuels would produce enough CO_2 to head Earth back toward the ice-free state, a different planet than the one that humans know.

#12 Climate also fluctuates on shorter time scales, as shown by this record of Antarctic temperature for the past 400,000 years. Civilization developed during the Holocene, the relatively stable warm period, now almost 12,000 years long. During the last ice age New York was under a kilometer of ice and sea level was 350 feet lower.

The glacial to interglacial climate swings are caused by perturbations of Earth's orbit. As Jupiter, Saturn and Venus tug at our planet, Earth's spin axis tilts successively slightly more toward or away from the sun. Also Earth's orbit becomes more or less eccentric. These changes alter the amount of sunlight striking the ice sheets in the summer.

As ice sheets melt they expose a darker surface that absorbs more sunlight, causing Earth to become slightly warmer. The warming ocean releases CO_2 to the atmosphere and the greenhouse effect of this CO_2 causes additional warming. Changing ice sheet size and changing atmospheric CO_2 are slow feedbacks that amplify the climate change.

#13 Indeed, these feedbacks cause almost the entire temperature change. The sea level record in the top curve tells us how large the ice sheets were. Greenhouse gas amount is known from bubbles of air trapped in the Antarctic ice sheet as snow piled up.

Multiplying the ice sheet plus greenhouse gas forcings by a climate sensitivity of ¾ degrees Celsius for each watt of forcing yields good agreement with the actual climate change, as sown by the lower curves. This empirical climate sensitivity includes all fast feedback processes such as changes of water vapor, clouds, sea ice and aerosols – and it is much more accurate than can be obtained from climate models. The climate sensitivity for a specified greenhouse gas change becomes twice as large if we wait long enough for ice sheets to respond.

#14 The climate sensitivity and response time of the climate system are important, because humans have caused greenhouse gases to increase in the past century far outside the range of the past several million years, as shown by the expanded time scale on the right. Earth has begun to warm, as shown by the lower curve, but much of the warming is still in the pipeline, due to the long climate response time.

#15 To understand modern climate change we must know all climate forcings, that is, perturbations to Earth's energy balance. Greenhouse gases are accurately measured – they cause a large positive (warming) forcing. Human-made fine particles in the air (aerosols) reflect sunlight and thus cause cooling, but it is very uncertain, because it is not measured. Natural forcings, due to the sun and volcanoes, are probably larger now than in the eighteenth century, when the sun is believed to have been slightly dimmer and volcanic eruptions were greater. But the natural forcings are small compared to present human-made forcings.

The net climate forcing is probably between +1 and +2 watts per square meter. Carbon dioxide is the largest forcing, and as time goes on it will be more and more dominant because of its long lifetime in the atmosphere.

#16 In my University of Iowa talk in 2004 I used this photo of my daughter's children to discuss climate forcing. Sophie explains that the net forcing is about 2 watts, equivalent to two tiny light bulbs over each square meter of Earth's surface. But Connor could only count 1 watt. Connor may be right. We are not measuring aerosol forcing well enough to know for sure.

#17 So I went back to Sophie and Connor a few years later, when they were older and wiser. I asked them "what is the net climate forcing?" They said that they don't know. Well, we can't blame them if we adults fail to make the measurements.

But my grandchildren were useful in another way. They forced me to keep speaking out. I decided that I didn't want my grandchildren in the future to say "Opa understood what was happening, but he never made it clear."

#18 The upper graph shows estimates of changing climate forcings over the past century. Greenhouse gas forcing becomes increasingly dominant. Aerosol forcing is very uncertain, because it is not well measured.

If we use these forcings in a climate model with equilibrium sensitivity ¾°C per watt of forcing, we find good agreement with observed global temperature, as shown in the lower graph. This agreement could be partly accidental: if we used a model with greater sensitivity and a smaller climate forcing, or vice versa, we might also get agreement. However, the model's sensitivity agrees with the fast-feedback climate sensitivity implied by paleoclimate data.

#19 The most fundamental check of the physics is the planet's energy imbalance. We anticipate that the planet is out of balance, more energy coming in than emitted to space. That imbalance is the signature of the greenhouse effect, the smoking gun that can confirm climate change is being driven by a forcing. Imbalance is expected because greenhouse gases reduce the planet's heat radiation to space.

How can we measure Earth's energy imbalance? Small amounts of energy go into warming the atmosphere, melting ice, and warming the upper tens of meters of the ground, but most of the excess energy must go into the ocean, which has enormous heat capacity. Measuring the ocean's heat content accurately has been a great challenge, but the data are improving as more than 2000 ARGO floats have been distributed around the world ocean. Each float regularly yoyos an instrument package to a depth as great as 2000 meters.

The best data, covering the past 6 years, indicate that the planet is out of energy balance by at least ½ watt per square meter. These data are for the time of minimum solar irradiance in the 10-12 year solar cycle. Our climate model yields an imbalance of ¾ of a watt averaged over the solar cycle. I expect we will find close agreement with the model as the observations extend over the full solar cycle and the entire ocean. The data already show that the planet is out of energy balance, confirming the expected effect of human-made greenhouse gases.

#20 Global observations reveal effects of Earth's energy imbalance. The area of Arctic sea ice began to be measured by satellites in the late 1970s. The area of sea ice at the end of the melt season has decreased about 30 percent. There are large year-to-year fluctuations because of weather variations that affect the wind direction and ocean currents. But, because of the planet's energy imbalance, the area of sea ice will continue to decrease on decadal time scales. Unless we restore the planet's energy balance, we can expect to lose all late-summer sea ice within the next few decades.

#21 The area on Greenland that has summer snow melt, shown in red, fluctuates from year-to-year, depending on the weather. But the melt area has increased about 50 percent over the past few decades.

#22 Meltwater runs to a low spot on the ice sheet and burrows a hole, a vertical shaft that goes all the way to the base of the ice sheet. This water lubricates the base of the ice sheet.

#23 Increased meltwater is one of the processes speeding up discharge of giant icebergs to the ocean. The net effect was once uncertain, because global warming also increases the amount of water vapor in the air, so snowfall over the center of the ice sheet is increasing.

#24 But beginning in 2002 the gravity satellite, GRACE, began making measurements of the Earth's gravitational field with such high precision that we can measure the change of ice sheet mass. The Greenland ice sheet gets heavier in the winter as snowfall piles up and loses mass in the melting season. But overall Greenland is now losing more than 200 cubic kilometers of ice per year. Antarctica is losing more than 100 cubic kilometers per year. The data suggest that the rate of mass loss may be increasing.

#25 Another expected effect of global warming is expansion of subtropical dry regions. The overturning circulation, rising air in the tropics with subsidence in the subtropics, which gives rise to the dry subtropics, is expected to expand poleward as the planet warms. Observations show that expansion by 4 degrees of latitude, averaged over all longitudes, has occurred already.

The expanding subtropics affects the southern United States, the Mediterranean region, and Australia, for example. It is one of the reasons that Lake Mead and Lake Powell are only half full.

#26 The expanding subtropics is also one of the reasons for the increase in fires in the western United States, Greece and Australia. With the changing climate the fires burn hotter, making it more difficult for forests to recover.

#27 Another impact of global warming is the world-wide recession of mountain glaciers. Glaciers are receding in the Rocky Mountains, the Andes, the Alps, the Himalayas. Glacier National Park in the United States will need a new name within 25 years, because it will have no glaciers if greenhouse gases continue to increase.

Loss of glaciers has a practical impact, because in the driest months more than half of the water in major rivers, such as the Indus and Brahmaputra, is provided by glacier melt water. Without glaciers, floods from spring snowmelt will be greater and rivers will tend to run dry in the driest months.

#28 Coral reefs are the rainforests of the ocean, home to more than a quarter of ocean species. Coral reefs are under stress for several reasons. Two of the most important stresses are the warming waters and ocean acidification. Warming can cause coral bleaching and death as the coral expel their symbiotic algae. The ocean becomes relatively more acid as it takes up carbon dioxide, which is a problem for animals with carbonate shells or skeletons – if the water becomes too acid it can dissolve carbonates.

#29 Such phenomena help us assess the atmospheric carbon dioxide amount required to maintain life on our planet as we know it. Each of these phenomena, including their responses to current levels of atmospheric CO_2, lead to the conclusion that the target atmospheric CO_2 amount that we must aim for is less than the current amount, which is 389 ppm in 2010.

The best, most quantitative, assessment is the need to restore planetary energy balance. Stabilizing climate, stopping global warming, requires restoration of Earth's energy balance – as long as there is more energy coming in than going out, the planet will keep getting warmer. The present imbalance is at least ½ watt per square meter. A ½ watt increase of thermal emission to space can be achieved by reducing atmospheric CO_2 by 35-40 ppm.

The optimum CO_2 may be somewhat less than 350 ppm, especially if there are future reductions in atmospheric aerosols. However, adjustments of other forcings such as methane and black soot can help balance such effects.

#30 For policy purposes all we need to know for the foreseeable future is that the CO_2 target must be "<350 ppm", if we wish to preserve creation, the planet on which civilization developed. Bill McKibben and the young people who form the backbone of the organization 350.org have done a remarkable job of publicizing the need for this target. They have succeeded in getting more than 100 nations to agree to this target.

#31 What is the practical implication of the "<350 ppm" target? This chart shows the amount of carbon in fossil fuel reservoirs, dark purple areas being the portion that has already been burned and released into the air. There is a range of estimates for the remaining reserves, which depend in part on whether we will go after "every last drop."

In order to stop growth of atmospheric CO_2 and return to a level below 350 ppm, we must phase out coal emissions rapidly and leave most of the "other" fossil fuels, the unconventional fuels such as tar sands, in the ground. In that case atmospheric CO_2 could peak at a value between 400 and 425 ppm, depending upon how much of the remaining oil and gas we exploit.

If we do not go after every last drop of oil and gas, it will be possible to get CO_2 back below 350 ppm within several decades, provided that we also adopt improved agricultural and forestry practices that cause more CO_2 to be stored in the vegetation and soil.

#32 So it is possible to achieve the 350 ppm CO_2 target, but there are 3 essential actions. First, coal emissions need to be phased out rapidly. Second, the unconventional fossil fuels should be left in the ground. Third, we should not pursue every last drop of oil and gas.

In other words, we must move on to the clean energy future now, rather than using all the remaining fossil fuels.

#33 But what is really happening? The United States has signed an agreement with Canada for a pipeline to carry tar sands oil to Texas. New coal plants are being built all around the world, some being financed by the World Bank. Environmentally destructive mountaintop removal continues. Oil is pursued in pristine places. The environmentally destructive practice of shale fracturing is being developed and implemented to find the last bits of gas.

#34 There is a huge gap between government rhetoric and policy reality. Leaders say that we have a "planet in peril," yet their proposed policies barely differ from business-as-usual.

Greenwash is plentiful, but the leaders follow a path of appeasement of fossil fuel special interests. There is no Winston Churchill willing to stand up and tell the truth about what is needed.

International agreements are jury-rigged to allow continued business-as-usual. For example, the World Bank is allowed to finance new higher efficiency coal plants in developing countries and count these as a "clean development mechanism", which allows dirty plants in developed countries to continue. Total CO_2 emissions actually increase. The science requirement is that the coal be left in the ground, because fossil fuel CO_2 stays in the atmosphere-ocean system for millennia. It does not help to burn it more efficiently.

#35 CO_2 emissions were increasing 1.5 percent per year prior to the Kyoto Protocol. Subsequently emissions have increased 2.5 percent per year, even with the recent economic downturn.

#36 Fossil fuel use continues to increase because fossil fuels are the cheapest energy. It is as certain as the law of gravity: as long as fossil fuels are the cheapest energy their use will continue. Fossil fuels are cheapest in part because they are subsidized, but mainly because they are not made to pay their cost to society – caused by their impact on human health, on the environment, and on the future of young people.

The solution is obvious: remove subsidies and put a rising price on carbon – a fee collected domestically from the fossil fuel companies at the mine or port of entry.

Of course efficiency regulations are also needed, as is technology development – but the success of these depends on having a rising carbon price.

#37 The public will accept a substantial rising carbon fee only if the money is distributed to the public. Put the money in the hands of consumers and let the market place choose technology winners. Those citizens who do not use their resources to reduce their carbon emissions will soon be paying more in increased energy prices than they get in their green check.

A carbon fee or tax is the only viable global approach. It requires mainly that the United States and China agree upon a carbon price. Europe and Japan would surely then consent. Any country not agreeing would have a duty placed on its products made with help of fossil fuels.

#38 Cap-and-trade, in contrast, is favored by big banks and fossil fuel interests. In a multi-trillion dollar carbon market it is impossible to avoid bank involvement. Their highly skilled, secretive, trading units would make billions, without providing any added value.

Cap-and-trade is proven to be ineffectual in reducing emissions and it cannot be made global. India and China would never accept caps on their economies, nor should they.

#39 Fee-and-green-check puts money in the public's hands, a lot of money, stimulating the economy and stimulating innovation. It is the fastest route to a clean energy future. It would quickly bring mountaintop removal and tar sands development to an end – it may be the only way to do that, surely the least painful way.

#40 Back to the basic issue: stabilizing climate is a matter of intergenerational justice. Jake, my son's first child, recently was excited to have a baby sister, who was 2½ days old in this photo. My parents lived about 90 years, so Jake and Lauren Emma are likely to be around most of this century and feel the full force of climate change.

#41 Jake likes to protect his baby sister, even though she is sometimes a nuisance. Jake is a gentle giant, for his age. If you believe long extrapolations, the charts suggest that he may be almost 2 meters tall eventually. But here is the problem: protecting Lauren Emma may be out of Jake's control, no matter how big and strong he is.

Today we have pushed the planet close to tipping points. Ice is melting in the Arctic, on Greenland and Antarctica, and on mountain glaciers worldwide. Many species are stressed by environmental destruction and climate change. If fossil fuel emissions continue unabated, sea level rise and species extinction will accelerate out of humanity's control. Increasing temperature and atmospheric water vapor will magnify climate extremes, both droughts and floods, and the storms of our grandchildren will be much more devastating.

#42 Such intergenerational injustice is foreign to all nations, cultures and religions. Yet we are saddled with governments who do nothing effective. They think they can set emissions at whatever level they choose, and they choose it with the help of the fossil fuel industry.

This situation is likely to continue until the public demands that governments do their job. But prospects for pressure from the public have been diminished by an effective campaign to discredit science by those who prefer business-as-usual.

#43 Yet I see 2 reasons for some optimism. First, China seems capable of making rational decisions and taking action. China has several incentives to move as rapidly as practical into clean energies: (1) their high levels of local air and water pollution, (2) the fact that they will suffer more from global warming than most nations, and (3) the economic advantage that they can gain by being out front in clean energy technologies. Indeed, China is aggressively investing in clean energy technologies.

Will this action by China stimulate the United States and other nations to get moving? Maybe. But, because of the undue influence of money in Washington and other capitals, I believe it is essential to involve the judicial branch of governments. As in the case of civil rights, achievement of justice probably requires people standing up for their rights and courts enforcing them.

#44 Legal scholars point out that governments have a fiduciary responsibility to manage the atmospheric trust. The executive and legislative branches of our governments are turning a deaf ear to the science, but the courts have the ability to require the government to make emission reductions that the science shows to be necessary. Stabilizing climate is a matter of intergenerational justice that can be enforced.

Young people, and older people who support them, must unite in demanding an effective approach that preserves our planet. I look forward to working with young people and their supporters in developing the scientific and legal case for young people and the planet.

To the young people I say: Stand up for your rights. Demand that the government take the actions needed to assure a future for you and your children. To the old people I say: we are not too old to fight. Let us gird up our loins and prepare to fight on the side of young people for protection of the world that they will inherit.