Global Warming Time Bomb:*
Actions Needed to Avert Disaster

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***Any statements relating to policy are personal opinion**

Global warming IS a time bomb.

There may still be time to defuse it, but that requires policy-makers to take the actions that are needed, not the ineffectual actions they are discussing.

Global Warming Status

1. Knowledge Gap Between
- **What is Understood (scientists)**
- **What is Known (public)**

2. Planetary Emergency
- **Climate Inertia → Warming in Pipeline**
- **Tipping Points → Could Lose Control**

3. Bad News & Good News
- **Safe Level of CO_2 < 350 ppm**
- **Multiple Benefits of Solution**

Despite the publicity that global warming has received, there is a large gap between what is understood by the relevant scientific community, and what is known by the people who need to know, the public and policymakers

Global warming is small compared to day-to-day weather fluctuations, so it is hard for people to recognize that we have a crisis – but we do.

The climate system has great inertia, caused, e.g., by the 4-kilometer-deep ocean and the thick ice sheets on Antarctica and Greenland – they have only partly responded to the human-made changes of atmospheric composition. But that inertia is not our friend – it is a Trojan horse – by the time the public notices that change is underway the momentum of the climate system may be sufficient to guarantee much larger changes. The climate system can pass tipping points, such that large change continues out of our control.

The bad news is that we have already passed into a dangerous range of atmospheric carbon dioxide. The good news is that if we act smart and promptly it is still feasible to achieve a safe level of atmospheric gases, and the actions needed to achieve that would have multiple benefits in addition to climate stability.

Climate Tipping Points

1. Ice Sheet Disintegration

- Ocean Warming → Ice Shelves Melt → Ice Streams Surge → Disintegration

2. Species Extermination

- Shifting Climate Zones, Multiple Stresses, Species Interdependencies

3. Methane Hydrate 'frozen methane'

- In Tundra & On Continental Shelves

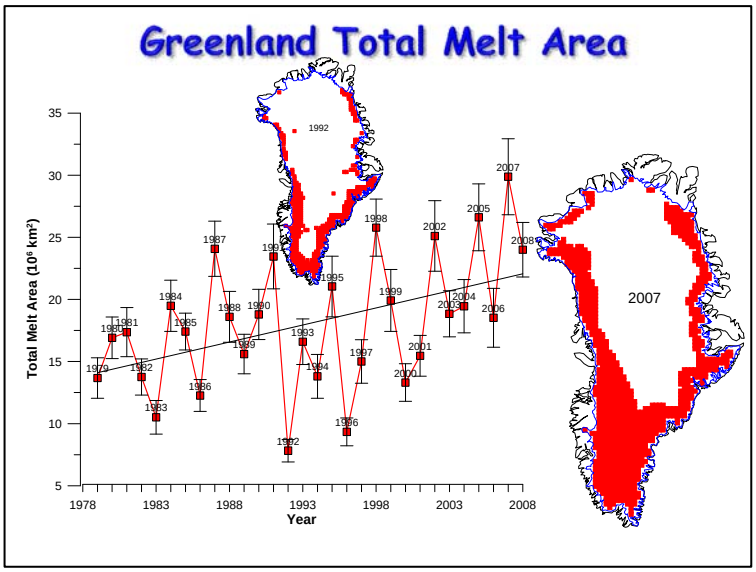
- Depends On Ocean & Ice Sheets

Here are several climate tipping points of special concern. Tipping points are "non-linear" phenomena, which means that they can reach a point at which rapid catastrophic change occurs. It is inherently difficult to determine the time at which non-linear collapse will occur, even in cases where such rapid change is certain.

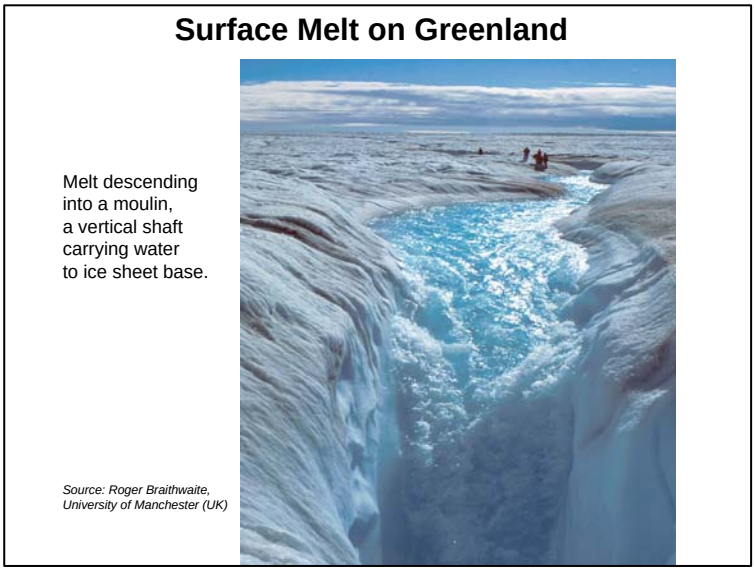
The mechanism that seems to be most important for disintegration of the great ice sheets that cover Antarctica and Greenland begins with ocean warming. Ocean warming leads to melting of ice shelves, which are tongues of ice that stretch out into the ocean. The ice shelves buttress the ice sheets, so when ice shelves disappear the more mobile parts of the ice sheet, the ice streams, can surge into the ocean – thus removal of the ice shelves is somewhat akin to taking the cork out of a bottle – it allows the material behind to flow rapidly. We know from Earth's history that once ice sheet disintegration is well underway, sea level can rise by several meters per century.

Species extermination is also a non-linear problem. Today we are placing many species under multiple stresses, but one stress that is growing rapidly is the shifting of climate zones due to global warming. An average temperature line has been moving poleward at a rate of 50-75 kilometers per decade during the past three decades. As the total movement of climate zones becomes larger it threatens those species that are less mobile. Because of interdependencies of species, the loss of key species can cause entire ecosystems to collapse.

Methane is an especially powerful greenhouse gas. There are large amounts of methane presently locked up, frozen, in high latitude tundra and, especially, in ocean sediments on continental shelves. We know from Earth's history that this frozen methane can be released suddenly by sufficient warming – thus this methane has the potential to greatly amplify human-made global warming, if that warming reaches a level, a tipping point, such that large volumes of frozen methane begin to melt.



Let's look more at processes contributing to ice sheet disintegration. We have accurate satellite measurements of the area on Greenland with summer melting on the snow and ice surface. The area with melting fluctuates from year to year, depending on year-to-year weather fluctuations, but there is a long-term increase of the melt area. The area with summer melting is shown by the red area, with maps for 1992 and 2007, the years with the least and most melt area. The trend has an increase of 50 percent in melt area during the past three decades. [Credit: Konrad Steffen]



The meltwater runs to a low spot on the ice surface, where it burrows a hole in the ice sheet that carries the water all the way to base of the ice sheet.

Jakobshavn Ice Stream in Greenland

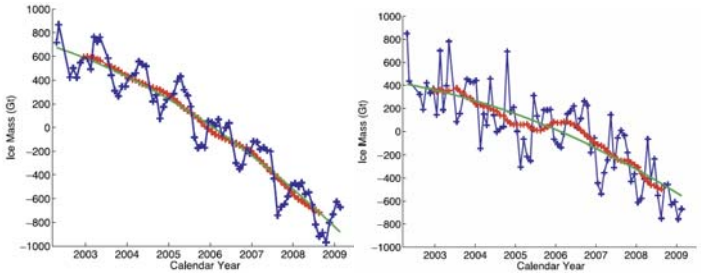
Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado

The meltwater lubricates the base of the ice sheet, accelerating the discharge of giant icebergs to the ocean. This is one of the processes causing ice loss from Greenland and Antarctica to increase.

Another process, probably even more effective than surface melt, is melting of ice shelves by warmer ocean water. Ice shelves are tongues of ice extending from the large ice sheets into the ocean. The ice shelves buttress the large ice sheet, helping to keep it in place. As a warming ocean melts the ice shelves, icebergs begin to stream more rapidly into the ocean.

Gravity Satellite Ice Sheet Mass Measurements



Greenland Ice Sheet **Antarctic Ice Sheet**

Source: Velicogna, I. *Geophys. Res. Lett.*, **36**, L19503, doi:10.1029/2009GL040222, 2009.

Until recently, some scientists argued that global warming may cause ice sheets to grow, because a warmer atmosphere holds more water vapor and thus produces greater winter snowfall. Of course, common sense suggests that the ice sheets will become smaller as the planet becomes warmer, but accurate measurements are needed to prove what is happening.

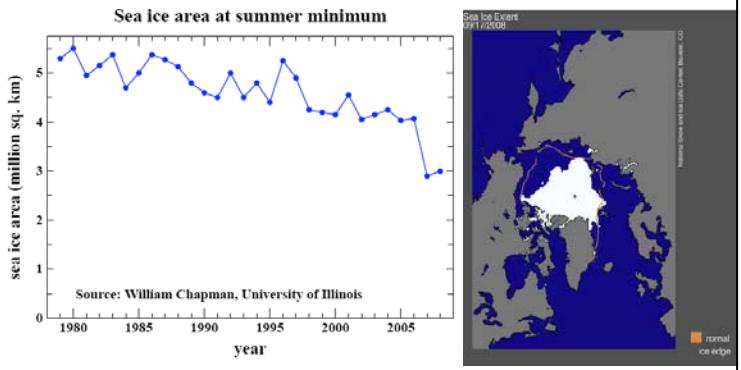
Beginning in 2002 precise measurements of Earth's gravitational field were made by the NASA GRACE satellite. The gravity data yield accurate measurements of changes of the mass of the ice sheets. As the figure shows, the mass of Greenland increases with winter snowfall and decreases with summer snow melt. Overall, Greenland is losing mass at a substantial rate. Earlier this decade Greenland was losing mass at a rate of nearly 200 Gigatons per year. In the past few years the mass loss has increased to almost 300 Gigatons per year. One gigaton is the mass of one cubic kilometer of water.

The status of the Antarctic ice sheet is even more important. The West Antarctic ice sheet is vulnerable to possible rapid disintegration, because much of that ice sheet is grounded on bedrock well below sea level – so a warming ocean could potentially dislodge the West Antarctic ice more readily than ice that is sitting on land above sea level. The West Antarctic ice sheet contains enough ice to raise sea level by about seven meters.

The right side of the figure shows that Antarctica overall is losing ice mass. In the past few years the rate of Antarctic mass loss has increased, with the recent rate being close to 200 cubic kilometers per year.

Earth's history reveals numerous cases in which ice melt caused sea level to rise several meters per century. If business-as-usual greenhouse gas emissions continue the human-made climate forcing will be much greater than the natural forcings that caused these earlier ice sheet disintegrations. I find it implausible that the West Antarctic ice sheet could survive this century, if business-as-usual emissions continue. Thus, in such an emission scenario, sea level rise of several meters should be expected this century, with still further sea level rise continuing, out of control of humanity.

Arctic sea ice area at summer minimum.



Arctic sea ice is another potential tipping point of the climate system. The area of sea ice at the end of the summer began to be measured accurately from satellites in the late 1970s. The graph shows that the area of sea ice fluctuates from year to year, based on variable weather patterns. However, overall there has been a decline in sea ice area over the past three decades. In 2007 there was a sharp decline of sea ice area, to an amount just over half of the ice area three decades earlier.

Although sea ice recovered slightly in 2008 and even more in 2009, most analyses indicate that all summer sea ice will be lost within the next few decades, if business-as-usual greenhouse gas increases continue. It is difficult to imagine that the Greenland ice sheet could survive, if the Arctic sea ice disappears in summer.

Stabilization of Arctic sea ice requires, to first approximation, that Earth's energy balance is restored. At present, because human-made greenhouse gases have reduced the amount of heat radiation that Earth is emitting to space, the planet is out of energy balance by about 0.5 watts per square meter, uncertain by about 0.25 watts per square meter. Other things being equal, the amount of carbon dioxide in the air would need to be reduced from its present 387 ppm (parts per million) to about 350 ppm in order to increase emission of heat radiation to space by 0.5 watts per square meter and restore Earth's energy balance.

Pier on Lake Mead

Subtropics are expected to expand with global warming.

Observations show, on average, 4 degrees of latitude expansion.

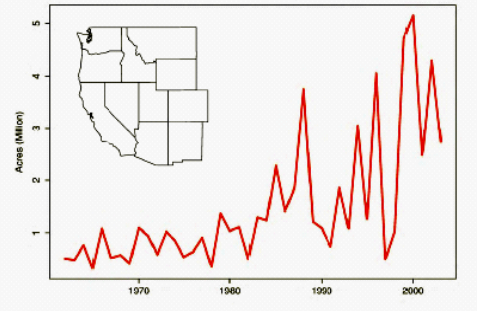
An important practical impact of global warming is the shifting of climate zones. The atmosphere's average overturning circulation, with rising motions in the tropics and sinking air that forms dry subtropical belts in both hemispheres, is expected to expand as the planet becomes warmer. Observations show that the subtropics have already expanded poleward, on average, by about four degrees of latitude.

Expansion and intensification of subtropical regions is already noticeably affecting the southern United States, where Lake Powell and Lake Mead are now only about half full, and the Mediterranean region. In the Southern Hemisphere, Australia and parts of Africa are affected.

Fires Are Increasing World-Wide

Wildfires in Western US have increased 4-fold in 30 years.

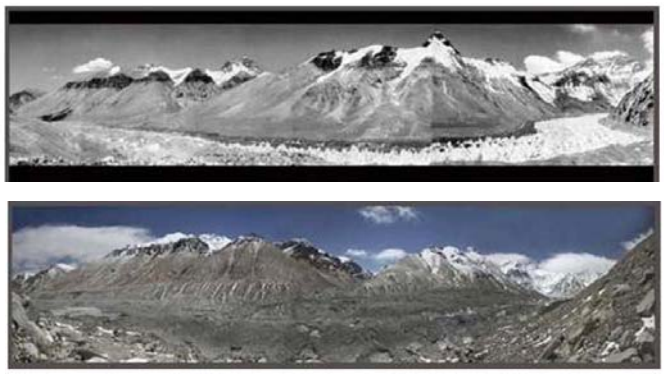
Western US area burned



Source: Westerling et al. 2006

One effect of increasing climate extremes is an increase in the frequency and intensity of wildfires. In the western United States, wildfires have increased four-fold during the rapid warming of the past 30 years.

Rongbuk Glacier



Rongbuk glacier in 1968 (top) and 2007. The largest glacier on Mount Everest's northern slopes feeds Rongbuk River.

Mountain glaciers are melting rapidly all over the world. If we continue with business-as-usual, most glaciers will disappear entirely within 50 years.

The loss of glaciers has great practical impact. Seasonal melting of glaciers provides fresh water for billions of people, storing water during the winter and releasing it slowly in warm seasons. During the dry season more than half of the water in great rivers such as the Ganges and Brahmaputra is meltwater from glaciers. Once the glaciers are gone, melting of increasingly large winter snowfall will cause great spring floods, but the rivers will run dry in the seasons when water is most needed.

Stabilizing mountain glaciers requires both restoring the planet's energy balance by reducing greenhouse gas levels and reduction of black soot aerosols, which darken the surface of glaciers.

Stresses on Coral Reefs

Coral Reef off Fiji
(Photo credit: Kevin Roland)

Coral reefs are the rainforest of the oceans, the site of between a quarter and a third of ocean species. Coral reefs are under stress for several reasons, but two of the most important stresses are caused by increasing greenhouse gases.

Ocean acidification is caused by increasing atmospheric carbon dioxide. As the ocean becomes more acid, animals with carbonate shells or carbonate skeletons and less able to survive. Indeed, sufficient acidity dissolves the carbonate.

A warming ocean surface is also a stress for coral reefs – it causes a "bleaching" as too-warm temperatures cause the coral to expel their symbiotic algae.

Assessment of Target CO_2

Phenomenon	Target CO_2 (ppm)
1. Arctic Sea Ice	**300-350**
2. Ice Sheets/Sea Level	**300-350**
3. Shifting Climatic Zones	**300-350**
4. Alpine Water Supplies	**300-350**
5. Avoid Ocean Acidification	**300-350**

→ Initial Target CO_2 = 350* ppm

***assumes CH_4, O_3, Black Soot decrease**

We can estimate the target level of atmospheric carbon dioxide that we must aim for by considering several phenomena that are already being affected by climate change and increasing carbon dioxide.

The most fundamental requirement is to restore the planet's energy balance. At present, averaged over several years, our best estimate is that the planet is out of balance by about one-half watt per square meter, with uncertainty of about one-quarter watt per square meter. If other factors remained unchanged, restoration of Earth's energy balance requires reducing atmospheric carbon dioxide from its present 387 ppm to about 350 ppm.

Conceivably it will be necessary to return carbon dioxide even closer to its pre-industrial value of 280 ppm, especially for matters such as ice sheet stability and sea level. However, it is probably undesirable to return carbon dioxide fully to its pre-industrial level, as humans have also introduced negative (cooling) climate forcings, via atmospheric aerosols and changes of surface reflectivity.

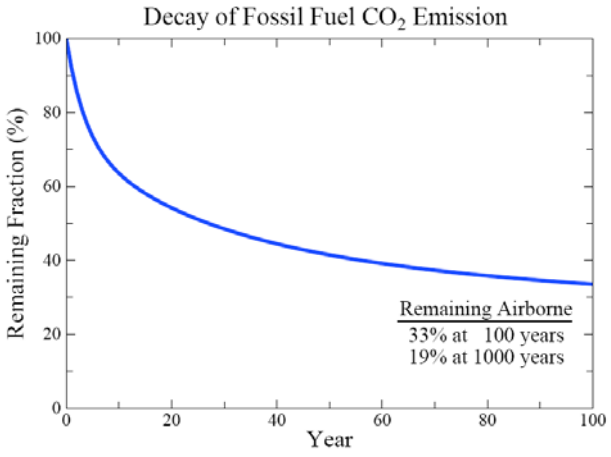
There is no practical need to define the carbon dioxide target more precisely now – the goal "less than 350 ppm" already tells us all that is needed for policy purposes for the foreseeable future.

Target CO_2:

< 350 ppm

To preserve creation, the planet on which civilization developed

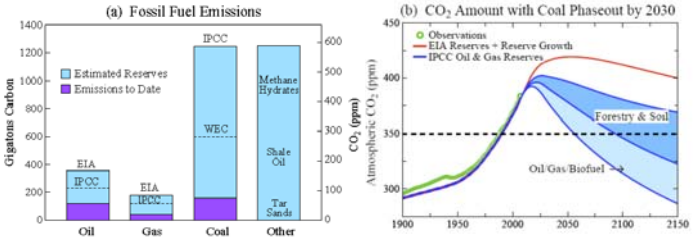
We must take actions to return atmospheric carbon dioxide from its present level of 387 ppm (annual global mean for 2009) to an amount no greater than 350 ppm if we wish to preserve a planet similar to the one we inherited from our elders, the planet on which civilization developed, a planet with stable shorelines and climate patterns like those for which our infrastructure has been developed.



The fraction of CO_2 remaining in the air, after emission by fossil fuel burning, declines rapidly at first, but 1/3 remains in the air after a century and 1/5 after a millennium (*Atmos. Chem. Phys.* **7**, 2287-2312, 2007).

When we inject a pulse of carbon dioxide into the atmosphere by burning fossil fuels, the carbon dioxide begins to disappear quite rapidly. After 25 years about half of it has been taken up by the land and ocean, mostly by the ocean.

However the ocean will not take up the full carbon dioxide emissions, because the carbon dioxide entering the ocean exerts a “back pressure” on the atmosphere – the carbon dioxide can come back out of the ocean. Until the excess carbon is deposited on the ocean floor as carbonate sediments the ocean will not take up all of the fossil fuel emissions. Formation of those sediments takes thousands of years.



Scenarios assume no "Other" = Tar Sands, Oil Shale, Methane Hydrates.

Coal phase-out by 2030 → peak CO_2 ~400-425 ppm, depending on oil/gas.

Faster return below 350 ppm requires additional actions.

Source: Hansen *et al.*, Target atmospheric CO2: where should humanity aim? *Open Atmos. Sci. J.*, **2**, 217-231, 2008.

The climate and geophysical facts yield a remarkably well-defined and important conclusion. The story is summarized in the two parts of this figure.

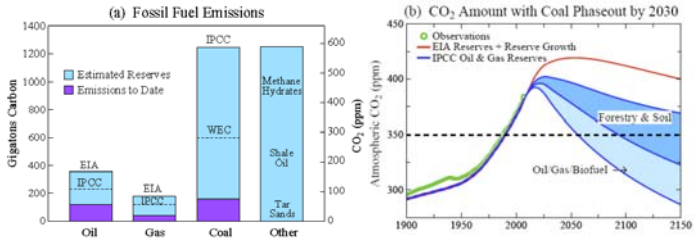
The bar graph shows the carbon contained in all fossil fuels, with purple indicating portions that have already been burned. The blue portions are estimated economically-recoverable reserves, which each have substantial uncertainty. What is economically recoverable depends strongly upon policies, e.g., whether fossil fuels are subsidized or, in contrast, a growing carbon price is adopted. The IPCC reserve estimate for coal is almost surely too large, and even the World Energy Council (WEC) estimate may be too high – but there is more than enough coal to take the world far into the realm of dangerous climate change. Oil and and gas reserves that are actually exploited might be kept closer to the IPCC estimates via a rising price on carbon emissions. The larger reserve estimates of the Energy Information Administration (EIA) may re realistic if a policy is pursued to extract every last drop of oil in the ground from public lands, off-shore areas, the deep ocean, and polar regions. Unconventional fossil fuels, e.g., tar sands, oil shale, and methane hydrates potentially contain an even greater amount of carbon, but most of these could be left in the ground, if a sufficiently high price on carbon emissions is established.

The right side of the chart compares actual atmospheric carbon dioxide history with carbon cycle simulations based on a dynamic-sink pulse-response function representation of the Bern carbon cycle model (Joos et al., 1996; Kharecha and Hansen, 2008). See the "Target" paper for a fuller discussion and complete references. The important point is that atmospheric carbon dioxide will peak at a value somewhere in the range 400 to 425 ppm, if coal emissions are phased out by 2030 and if unconventional fossil fuels are not used significantly. Improved forestry and agricultural practices could bring carbon dioxide below 350 by the end of this century via actions that draw down atmospheric CO2 by about 50 ppm. This result applies to the case in which the IPCC estimates for oil and gas reserves are valid, in other words, to the case in which a sufficient price is placed on carbon emissions to discourage extraction of every last drop of oil and gas. Still faster drawdown of atmospheric carbon dioxide can be achieved, as shown by the light blue area in part (b) of the figure, if carbon capture and sequestration is used in conjunction with oil and gas use, such as at power plants.

First grandchild, Sophie – at age almost two years

I will emphasize the intergenerational inequity of global warming. This is a photo of our first grandchild, taken several years ago. Some newspapers had described me as the grandfather of global warming, so for amusement I showed this photo – I really was a grandfather.

My grandchildren began to influence me when I realized that policy makers were ignoring the message from the climate science – or rather that politicians were developing the fine art of greenwash – they would say favorable words about the environment and stabilizing climate – but their actions were inconsistent with that goal. Politicians would be happy if scientists just tell them there is a climate problem and then go away and shut up – let them decide what they want to do. But I decided that I did not want my grandchildren, some day in the future, to look back and say "Opa understood what was happening, but he did not make it clear."



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Faster return below 350 ppm requires additional actions

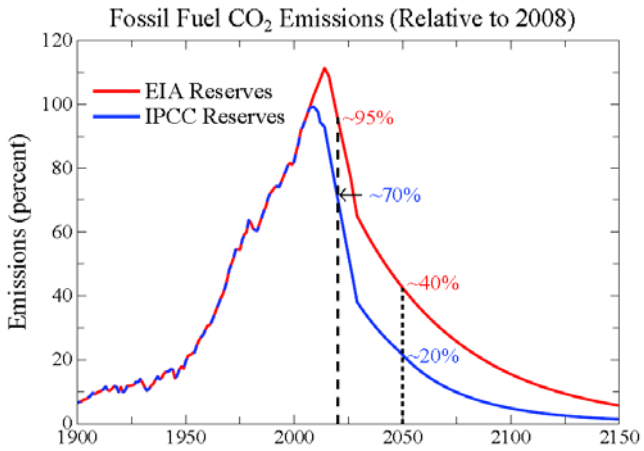
Source: Hansen *et al.*, Target atmospheric CO_2: where should humanity aim? *Open Atmos. Sci. J.*, **2**, 217-231, 2008.

What is clear is that we cannot burn all the fossil fuels. There is a limit on how much carbon we can put into the atmosphere.

These graphs tell us unambiguously that we must phase out all coal emissions rapidly, not develop the unconventional fossil fuels, and not even go after every last drop of oil on the planet. In that case, our children and grandchildren have a chance of inheriting a planet that is not spiraling out of their control.

In reality our governments are continuing to build new coal-fired power plants, develop unconventional fossil fuels, and encourage the search for more oil.

Instead of taking a strategic approach, governments pretend that they will solve the problem by setting "goals" for large emission reductions for some future date – say 80 percent by 2050 or some other target. They say that they will set "caps" on emissions to achieve the emission reductions. Our governments are lying to us, or, if you want to be generous, they are kidding us. That is easy to prove.



CO_2 emissions relative to 2008 if coal emission phased out linearly over 2010-2030

These graphs show how emissions will decline if coal use is phased out linearly over the next 20 years and if unconventional fossil fuels are prohibited. The two results (blue and red lines) are for the modest oil and gas reserves estimated by IPCC and for the larger reserves estimated by the United States Energy Information Agency.

With the small oil and gas reserves, depletion of those reserves will cause carbon emissions to fall to 20 percent of current emissions by 2050 and to 40 percent with the government estimates of oil and gas reserves. But that is assuming 100 percent coal phaseout and no use of unconventional fossil fuels. In reality, governments are not phasing out existing coal emissions, instead coal emissions are increasing. And governments are allowing unconventional fossil fuels to be developed. Thus it is inconceivable that government "goals" or "targets" for carbon dioxide emission reduction will be met. Governments stating such goals are lying to the public with a straight face.

Initial Target CO_2: 350 ppm

Technically Feasible

Quick Coal Phase-Out Necessary

No new coal w/o CO_2 capture
All coal phased out within 20 years

Carbon Price Essential

Fossil Fuel Costs > Alternatives
Avoid Unconventional Fossil Fuels

Preservation of a healthy planet, with a stable climate and containing most of today's species, is technically feasible.

But it requires prompt phase-out of coal emissions. And it requires a rising price on carbon – that is the only way that we can transition to the cleaner, healthier world beyond fossil fuels.

What's Really Happening (USA)

1. **Tar Sands agreement with Canada**
   - **Pipeline planned to transport oil**
2. **Oil Shale under development**
   - **Twice CO_2/energy of conventional oil**
3. **New Coal-fired power plants**
   - **Rationalized by 'Clean Coal' mirage**
4. **Mountaintop removal proceeds**
   - **Destroys wind potential of mountains**

But what is actually happening? It is quite the opposite, despite the presence of many greenwashing politicians. Here is a representative nation – the United States.

Global Action Status

1. **Huge Gap: Rhetoric & Reality**
   - **Rhetoric: Planet in Peril**
   - **Reality: Small Perturbations to BAU**
2. **Greenwash is Winning**
   - **Appeasement of Fossil Interests**
   - **Still Waiting for a Winston Churchill**
3. **Message to Young People**
   - **You're on Your Own Kids**
   - **Good Luck!**

Despite the rhetoric about a planet in peril, the reality is that fossil fuel companies are still calling the tune. We, the taxpayers, are still subsidizing fossil fuels. And fossil fuel companies are not made to pay for the damage that they do to human health or the planet's health.

The present situation is analogous to that faced by Lincoln with slavery and Churchill with Nazism—the time for compromises and appeasement is over.

But today we have no great leader with the intestinal fortitude to stand up to the special interests.

What's the Problem Today?*

1. **Fossil Fuels Priced Lowest**
   - Fossil Fuels Subsidized!
   - No Charge for Damages (Health, etc.)
2. **Governments Under Fossil Thumbs**
   - Greenwash Instead of Leadership
3. **Revolving Door in Washington**
   - # Lobbyists & Pay Exceed President's

*Just my opinions, of course

"Free Will" Alternative

1. **Phase Out Coal CO_2 Emissions**
   - by 2025/2030 developed/developing countries
2. **Rising Carbon Price**
   - discourages unconventional fossil fuels & extraction of every last drop of oil (Arctic, etc.)
3. **Soil & Biosphere CO_2 Sequestration**
   - improved farming & forestry practices
4. **Reduce non-CO_2 Forcings**
   - reduce CH_4, O_3, trace gases, black soot

Technical Priorities

1. **Energy Efficiency**
   - Standards & Carbon Tax Needed
2. **Renewable Energies**
   - Solar, Wind, Geothermal, Biomass…
3. **Next Generations of Nuclear Power**
   - 3rd Gen.: increased safety
   - 4th Gen.: burns waste, efficiency X 100
4. **Carbon Capture & Sequestration**
   - Cost, Coal Problems Remain, Use w Biofuels?

http://www.columbia.edu/~jeh1/2009/ECWorkshop_report.pdf

Carbon Fee & 100% Dividend

(consider: $115/ton CO_2 = $1/gal. gas)

1. **Yield ~ $670B (U.S. example)**
2. **Dividend (bank acct or debit card)**
   - Adult Legal Resident
     - ($250/month = $3000/year)
   - Family with 2 Children
     - ($750/month = $9000/year)

Fee & Dividend

1. **Fee Applied at First Sale/Port of Entry**
   - Covers all Oil, Gas, Coal → No Leakage
2. **Fee Specified: No Speculation, Volatility**
   - No Wall Street millionaires at public expense
3. **Requires United States, Europe, China**
   - Simple Negotiation, No Transfer of Funds
   - Can be Implemented in One Year
   - Duties on Products Made from Fossil Fuels Will Yield Prompt Global Compliance

Universality, Fairness

1. **Import Duties on Untaxed Products**
   - Standard Rates, Can Be Appealed
2. **Duties from Developing Countries Returned 100% (not uniformly)**
   - Amount Will Dwarf Current Foreign Aid
3. **Fairness, Reward Best Practices**
   - Use Duties for Adaptation, Countries that address Population (women's education)

Impossible to Solve, You Say?

Yes, Fossil Fuels Will All Be Burned!

O.K.,Then Tipping Points Will Be Passed

- **Ice Sheet Collapse, Mass Extinctions, Methane Clathrate Instability**

Start Thinking About Venus Syndrome

- **Economic and Social Chaos After Tipping Points Make Runaway Greenhouse Possible**

Jake: You're on your own baby – Good Luck!

Jake is our newest grandchild, our son's first child. He will probably be around for most of this century.

The message from Washington to Jake: You're on your own baby, good luck! Try geo-engineering! Jake seems to be wondering "what is geo-engineering?"

Intergenerational Justice

Jefferson to Madison: …self-evident that "the Earth belongs in usufruct to the living"*

Native Americans: obligation to 7th generation

Larry King: "nobody cares about 50 years from now"

Governments (with fossil interests): we can set emissions at whatever level we choose

Public: when will it become involved?

***Legal right to use something belonging to another**

Most cultures believe that we have a fiduciary responsibility to turn over to future generations a planet in as good a condition as we received from our parents.

If Larry King's impression of the public is right, young people and the planet may have little hope.

Our present governments are certainly not going to be the answer. The public, young people especially, must become involved and demand more.

Strategic Options

1. **Dialogue with Governments, but:**
   - **Their Perspective is Short-Term**
   - **Undue Sway of Money (lobbyists)**
2. **Courts**
   - **Common law – We are enjoying use of property that belongs to others**
3. **Public Protests and Actions**
   - **Seem Necessary, Are Growing**
   - **But Public has Other Concerns**

Web Site

www.columbia.edu/~jeh1

includes

Target Atmospheric CO_2: Where Should Humanity Aim?

Global Warming Twenty Years Later: Tipping Points Near

In Defence of Kingsnorth Six