

March 12, 2008

Office of the Governor  
Patrick Henry Building, 3rd Floor  
1111 East Broad Street  
Richmond, Virginia 23219

Dear Governor Timothy M. Kaine:

I am writing to you as a father and a grandfather because I am concerned about my children's future. For the sake of identification, I am the director of the NASA Goddard Institute for Space Studies, but I write to you as a private citizen, as Adjunct Professor at Columbia University, as a scientist who has worked in climate research for years, advising Congress, the Vice President, and Cabinet members about climate on multiple occasions.

It's for our children that our runaway emissions of carbon dioxide into the atmosphere will, if allowed to continue, prove catastrophic. Global warming is deceptive. It becomes irreversible at a time when its damage to the environment is practically imperceptible. Today we are treading perilously close to the tipping point.

That's why I appeal to you, the father of three school-age children, to use the strength of your leadership to rebuff one of the most powerful lobbies in your state and stop the coal industry's attempt to build a power plant in western Virginia.

Coal generates approximately 40% of the world's electricity—about half of America's. This energy comes at a price. Burning coal produces carbon dioxide, the gas most responsible for creating the greenhouse effect that is changing our climate. Yet coal is the cheapest and most abundant of the fossil fuels, and its worldwide use is soaring.

Twenty years ago I testified before the U.S. Congress that the planet was warming and that people were the cause. Then my analysis was controversial. Today human-made climate change is unambiguously underway. Arctic ice is melting at a faster rate than anyone had predicted. The Antarctic and Greenland ice sheets are at risk of disintegrating, with the sea level rising possibly out of control and inundating the land where millions of people live. Countless others face a future with less water, harsher droughts, and more severe storms.

Tipping points exist among people as well as climate systems. The action with the greatest potential to initiate positive feedbacks—to lead to the benefits that will accompany a clean-energy future—is a moratorium on new coal-fired power plants until the technology is developed to capture the carbon dioxide and store it underground, out of the atmosphere. Such a moratorium would do more than put the brakes on global warming. It would also provide the industrial world with sufficient moral authority to urge China and other developing countries to join the battle against climate change. As its name suggests, global warming is a global problem, and arresting it will take a global effort. At present, developing countries don't want to hear the rich guys tell them to curb their own, burgeoning use of coal and other fossil fuels. If the rich countries banned new coal plants, the developing world would be more likely to pay attention.

I am optimistic that greenhouse gas emissions can be reduced and atmospheric concentrations stabilized at levels short of disaster. But the chances diminish with each new coal-fired power

plant. That is why we must summon the leadership to declare that any new coal plant without the technology to capture carbon is off the table.

National sentiment is running against the coal companies. In Kansas, Democratic Gov. Kathleen Sebelius has halted a controversial coal plant. Florida Gov. Charlie Crist, a Republican, has done the same. They have gained the national spotlight while winning the support of their home-state constituents.

This puts you in an enviable position, Governor Kaine. You can save money for rate payers in Virginia at the same time that you help lead the world to a clean energy future, one that relies on non-polluting wind and solar power and better efficiency.

Concern about global warming is rising. Coal is on its way out. A governor who acts on both of these truths will go down in history as a true visionary.

Sincerely,

Dr. James Hansen  
Columbia University Earth Institute  
New York, NY 10027



# COMMONWEALTH of VIRGINIA

## Office of the Governor

L. Preston Bryant, Jr.  
Secretary of Natural Resources

P.O. Box 1475  
Richmond, Virginia 23218

April 15, 2008

**Dr. James Hansen**  
**Columbia University**  
535 West 116th Street  
New York, NY 10027-7041

Dear Dr. Hansen:

Thank you for your recent letter to Governor Kaine regarding the Virginia City Hybrid Energy Center (VCHec) and global warming, or climate change. The Governor has asked me to respond to you on his behalf, as the Department of Environmental Quality (DEQ), an agency of my secretariat, monitors Virginia's air quality.

The public comment period for the Virginia City Hybrid Energy Center's Prevention of Significant Deterioration air quality permit was open from January 12 through March 12, 2008. DEQ conducted hearings for this draft permit on February 11, 12, and 19, 2008. The draft permit establishes pollutant emission limits that meet or exceed all the federal and state regulatory standards for the project as proposed and would allow the plant to use not only coal but also waste coal piles and biomass, specifically wood. The draft permit also includes a plan developed by Dominion, the USDA Forest Service, and DEQ that ensures that the plant will not have a negative impact on any national forest or wilderness area. The draft permit requires that the energy center keep extensive records and provide reports on the other requirements of the permit.

VCHec, proposed for Wise County, Virginia, would utilize circulating fluidized bed boiler technology to make electrical energy. The U.S. Department of Energy recognizes this technology as a clean coal technology. The facility would be capable of using waste coal piles from the coalfield region of Virginia as fuel, which could help reduce the impact of undesirable runoff into Virginia streams. The new power plant would be designed and built so that it could be retrofitted with carbon capture or control technology in the future, when appropriate.

Both Governor Kaine and I agree that we need to reduce greenhouse gas emissions. In fact, the Virginia Energy Plan sets a goal for Virginia of reducing greenhouse gas emissions 30 percent below what they would otherwise be in 2025.

Dr. James Hansen

April 15, 2008

Page 2

Shortly after releasing the Virginia Energy Plan in September 2007, Governor Kaine established the Governor's Commission on Climate Change in December 2007. The Commission will prepare a plan for Virginia that identifies ways to reduce greenhouse gas emissions.

During the development of the plan, the Commission will take the following steps:

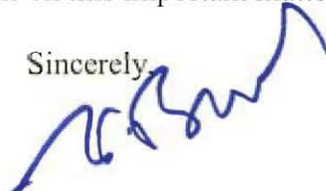
- Inventory the amount of and contributors to Virginia's greenhouse gas emissions, including emissions projections through 2025;
- **Evaluate the** expected impacts of climate change on Virginia's citizens, natural resources and economy;
- **Identify climate** change approaches being pursued by other states, regions and the federal government;
- Identify what Virginia needs to do to prepare for the likely consequences of climate change; and
- **Identify any actions** (beyond those identified in the Virginia Energy Plan) that need to be taken to achieve the 30 percent greenhouse gas reduction goal.

The Governor's Commission on Climate Change will identify additional steps that need to be taken to achieve the emissions reduction goal in a report scheduled to be issued by December 15, 2008. We believe the Commission's report will lead Virginia in the right direction as we try to combat this problem. After long and careful consideration, the Governor and I have acknowledged that global warming is a problem caused, largely, though not exclusively, by human activity (increased concentrations of greenhouse gases), and we are taking action to help resolve it. We believe this is the time for action, not debate.

More information about the Governor's Commission on Climate Change is available at [www.deq.virginia.gov/info/climate\\_change.html](http://www.deq.virginia.gov/info/climate_change.html). Information about the Virginia Energy Plan is available online at [www.naturalresources.virginia.gov/Initiatives/EnergyPlan/](http://www.naturalresources.virginia.gov/Initiatives/EnergyPlan/).

Thank you for sharing your concerns on this important matter.

Sincerely,

A handwritten signature in blue ink, appearing to read "L. Preston Bryant, Jr.", written in a cursive style.

L. Preston Bryant, Jr.

LBPJr/cbd

21 April 2008

To: Governor Tim Pawlenty

From: James Hansen, NASA Goddard Institute and Columbia University Earth Institute

Subject: A Plea for Your Further Leadership

Dear Governor Pawlenty,

I communicate with you as a fellow parent and former neighbor on a matter that will have great effects upon the lives of our loved ones. I grew up and was educated in Iowa, and my eldest sister has lived in St. Paul for more than half a century, with children, grandchildren and great grandchildren in the area.

The topic of concern is climate change, specifically global warming in response to human-made carbon dioxide (CO<sub>2</sub>) and other pollutants. This topic has long remained in the background, but it is now poised to become a dominant national and international issue in years ahead.

Global warming presents challenges to political leaders, but also opportunities. Minnesota has the potential to be a national leader by promoting development in areas that provide good jobs via technologies and practices that help ensure clean air and water while mitigating global warming. The facts that I will discuss are relevant to the proposed Big Stone II coal-fired power plant, and specifically they call for your continued strong leadership to help ensure Minnesota's future.

First, however, I want to make you aware of recent progress in understanding of global warming. Warming so far, averaging 2 degrees Fahrenheit over land areas, is smaller than chaotic weather fluctuations. Yet it already has noticeable effects and more is "in the pipeline", even without further increases of CO<sub>2</sub>, because of climate system inertia that delays the full climate response.

Global warming increases the intensity of both extremes of the hydrologic cycle, yielding heavier precipitation and floods, but also longer summers and more dried out fuel, allowing fires to ignite easier and spread faster. The wildfire season in the American West is now 78 days longer than 30 years ago, and the average duration of fires covering more than 2,500 acres has risen five-fold.

The world's leading climate researchers conclude that, if greenhouse gases continue to increase, the practical impacts will include:

- Longer and more intense droughts, thus widespread water shortages, especially in areas of high population growth and where water resources already are heavily utilized.
- More winter and spring flooding, but reduced summer and fall run-off, with some rivers in the American West in summer and fall reduced to a trickle in many years; this will intensify competition for over-allocated water resources.
- More intense precipitation and storms when it rains, with a resulting increase in flood risk.
- Longer and more intense summer heat waves, with a correspondingly adverse impact on public health, particularly for the elderly.
- Extinction of a large number of animal and plant species as shifting climatic zones adds to other human-induced stresses on the natural world.
- Disintegration of Antarctic and Arctic ice, with consequent rising sea level. The developed world, especially the United States, will bear much responsibility for resulting tragedies.

Minnesota is less in the immediate line-of-fire of sea level rise and water scarcity than some areas, but it cannot escape unscathed and economic repercussions will have no borders. The range of boreal forests will retreat into Canada and likely cause Minnesota to lose iconic species such as moose and stream trout, if atmospheric CO<sub>2</sub> is not stabilized. Minnesota industries of forestry and winter tourism, including skiing, snowmobiling and ice-fishing, depend upon the existing climate.

Governor Pawlenty, the scientific advances in just the past few years, paradoxically, carry both bad news and good news. The enclosed paper, "Target Atmospheric CO<sub>2</sub>: Where Should Humanity Aim" (<http://arxiv.org/abs/0804.1126> with Supporting Material at: <http://arxiv.org/abs/0804.1135>), makes clear that we have already passed the threshold of atmospheric CO<sub>2</sub> levels that we should allow to exist over the long-term. Mother Nature, as a friend of mine has noted, is wagging her finger at us, saying "Now you have gone too far!"

Consequences of ignoring this admonishment would be severe. As our mutual friend Will Steger has surely discussed with you, the Earth is nearing climate "tipping points" with potentially irreversible effects, including extermination of countless species, ice sheet disintegration and sea-level rise, and mass dislocation of populations.

The good news is that it is still feasible to solve the problem, to reduce CO<sub>2</sub> emissions over coming decades and draw down the atmospheric CO<sub>2</sub> amount through natural processes and with the help of improved agricultural and forestry practices. By drawing down the CO<sub>2</sub> amount we can not only avert catastrophic irreversible effects mentioned above, but also alleviate problems that were beginning to seem intractable and inevitable. I refer here to regional effects such as those discussed above, acidification of the ocean with destruction of coral reefs, and recession of alpine glaciers worldwide with accompanying loss of the principal freshwater source for hundreds of millions of people during the dry season.

Solution of the global warming problem has one unavoidable implication for fossil fuels. As the attached "Fossil Fuel Facts" make clear, atmospheric CO<sub>2</sub> can be successfully constrained only if coal use is phased out except where the CO<sub>2</sub> is captured and sequestered, so that it does not enter the atmosphere. In turn, this conclusion that coal use without sequestration must be phased out, over the next 20 years, foretells requirements and opportunities for Minnesota.

The imperative of halting coal emissions does not recognize state or national boundaries. There is no doubt about the eventual position of the United States and the international community. The mutual peril has become crystal clear and it will soon be widely understood. The United States, although it was also slow to enter prior international battles with the future at stake, surely will begin to exercise leadership in this matter, independent of political parties, because of the clarity of the threat to the planet. Disinformation campaigns, by the fossil fuel industry and utilities, cannot succeed, and they raise great liability risks.

Utilities and the fossil fuel industry must reckon with the fact that the laws of Nature and the human instinct for survival will overrule any paper agreements that may exist now or be wrangled in the near-term. "Grandfathering" of fossil fuel plants and any ineffectual "cap and trade" scheme, should it be initiated, will necessarily be replaced by "cap and bulldoze". Coal use must be eliminated unless and until technology is available with near-zero emissions.

Is it possible that I am wrong, that the governments are so larded with fossil fuel special interests that they will allow us to destroy the planet that we leave for our children and grandchildren? Sure

– just as there was a chance that the United States and the Soviet Union could have blown each other off the face of the planet with nuclear weapons – but it is much more likely that we will come to our senses soon, as the scientific story and empirical evidence overwhelm the deceit of short-term special interests.

One of the “Fossil Fuel Facts” is that a substantial fraction of fossil fuel CO<sub>2</sub> emissions stays in the air for what is, for all practical purposes “an eternity”, more than 1000 years. That is a well-established scientific fact – there is no debate. A direct implication is that we cannot be aiming for a 50, 80 or 90 percent reduction of emissions. We must transition over the next several decades to practically zero net CO<sub>2</sub> emissions. Thus our energy focus must be to develop carbon-free energy sources and energy efficiency.

I have no doubt that as a nation we have the ability to succeed. The technology already exists for low-loss transmission of electricity. Once a national low-loss grid exists we will be able to take full advantage of all renewable energies. Energy efficiency, however, will always be a priority, and, in the near-term, measures that remove barriers to efficiency are the most effective way to promote economic vitality and avoid the need for new power plants.

Governor Pawlenty, building Big Stone II, a conventional coal-fired power plant would expose ratepayers and Minnesota to grave financial risk. Steeply rising construction costs and coal prices are themselves ratcheting up the cost of coal-fired electricity, and sure-to-appear legislation that demands elimination of CO<sub>2</sub> emissions will drive costs much higher. Any assumption about possibly retrofitting the plant for CO<sub>2</sub> capture is a dubious and financially risky proposition.

A major additional disadvantage of coal is the pollution associated with it. There is no such thing as “clean coal”. Good stewardship of creation, of the planet that we inherited, suggests that the best place for coal is in the ground, where it is.

Although the fossil fuel industry pedals misinformation, claiming that renewable energies can only be a niche contribution to energy needs, that contention defies common sense. For example, the technology for solar thermal power stations already exists, power stations can be built rapidly, and as the market for them increases their unit costs will fall steadily, as the cost of coal power continues to rise. Wind energy is already economically competitive with fossil fuels, even without the certain carbon taxes visible on the horizon. Wind power can be exploited now in Minnesota, and as a low-loss grid is developed such renewable energy use will expand.

Note that the “fuel” for renewable energies (sunlight, wind, etc.) is cost-free and it will last practically forever. This is in stark contrast to coal. One reason the cost of coal has been shooting up is that coal is a finite resource requiring increasing efforts for extraction. The notion that the United States has a 200-year supply of economically extractable coal is a myth.

An indirect source of energy, with enormous potential, is efficiency. This potential can be tapped much more if rules for utility profits are changed such that profits increase when the utility helps customers improve efficiency, rather than when the customers use more energy.

Governor Pawlenty, I realize that there has been an unfortunate tendency for positions on energy issues to divide along party lines, (for the sake of disclosure, I am an Independent), but also that you have been a leader in recognizing the reality of climate change and appealing across party lines. This leadership and broad appeal can be maintained and burnished via a clear statement

opposing construction of any power plant that emits CO<sub>2</sub> and other pollutants. As governor, you can help inspire your state and the rest of the country to take the bold actions that are essential if we are to retain a hospitable climate and a prosperous future.

Specifically, a strong clear public statement by you against proceeding with construction of Big Stone II could be a turning point for Minnesota. It would provide a boost toward a future focused on renewable energies and energy efficiency, and the high-quality jobs that will be associated with that direction. Big Stone II, in contrast, poses severe risks for Minnesotans due to escalating capital costs, penalties for uncaptured CO<sub>2</sub> emissions, and environmental damage from changing climate as well as regional pollutants such as mercury.

I close on a note of optimism. I mention in my presentations the power gap in the face-off of fossil fuel interests against young people and nature. Fossil interests permeate state governments, as well as Washington. Young people must seem puny in comparison, and animals are of little help (don't talk, don't vote). Yet, as in our national revolution more than two centuries ago, the puny are united by a powerful force, a common goal for the common good. I am heartened that young people will make the difference in this war, on the side of nature and humanity.

Earlier this month I met remarkable young organizers, including Jessy Tolkan who led the New Voters Project in Wisconsin, registering over 130,000 18-24 year-old Wisconsin voters, making young people a powerful force in primary and general elections. These young people have now joined forces in a coalition of 47 youth organizations in support of bold climate action. The Energy Action coalition is determined to mobilize at least one million youth as a powerful force, on the side of nature and humanity, focused on the essential goal of zero carbon emissions as soon as humanly possible.

I recently learned that Energy Action, League of Young Voters, Rock the Vote, League of Young Voters, and the U.S. Student Association are all working in your state with young leaders from the University of Minnesota, University of St. Thomas, Macalater College, Carleton College, other institutions, and high schools. In addition to youth efforts, national conservation organizations including Environmental Defense, National Wildlife Federation, Clean Water Action and 1Sky are working in your state to engage voters on these issues.

Youth may still seem overmatched, aligned against fossil interests, but it would be a mistake for industry and political leaders to sell them short. They are not fooled by "green" advertisements of industry or token political actions. Leaders who put our nation on a course to carbon-free energy, allowing us to be good stewards of creation, of our planet, will find a strongly supportive public.

Respectfully,

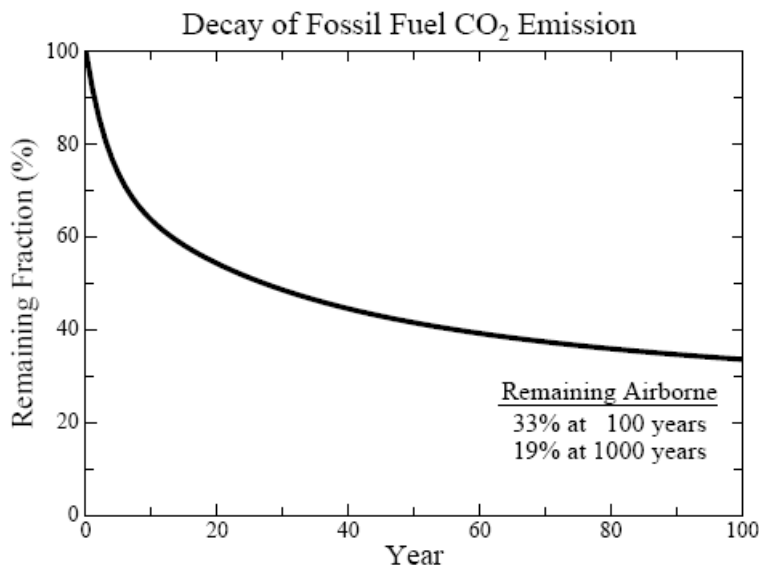
James Hansen

cc: Rep. Margaret Anderson Kelliher, Speaker of the House  
Rep. Marty Seifert, House Minority Leader  
Sen. Lawrence Pogemiller, Senate Majority Leader  
Sen. David Senjem, Senate Minority Leader



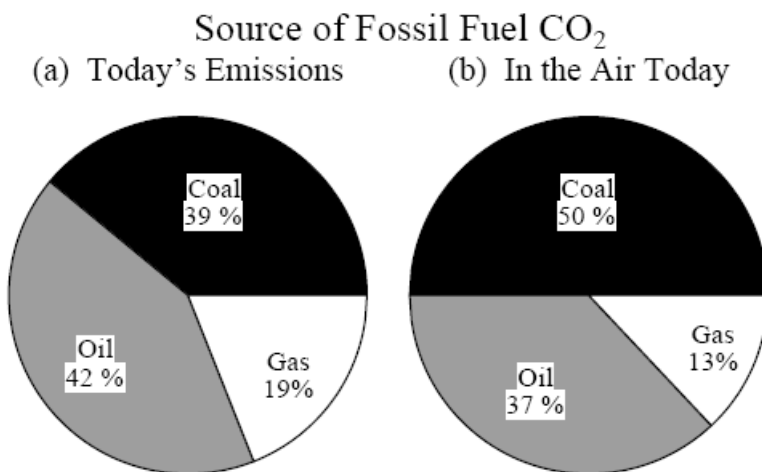
### Basic Fossil Fuel Facts

The role of coal in global warming is clarified by a small number of well-documented facts. Figure 1 shows the fraction of fossil fuel carbon dioxide (CO<sub>2</sub>) emissions that remains in the air over time. One-third of the CO<sub>2</sub> is still in the air after 100 years, and one-fifth is still in the air after 1000 years.

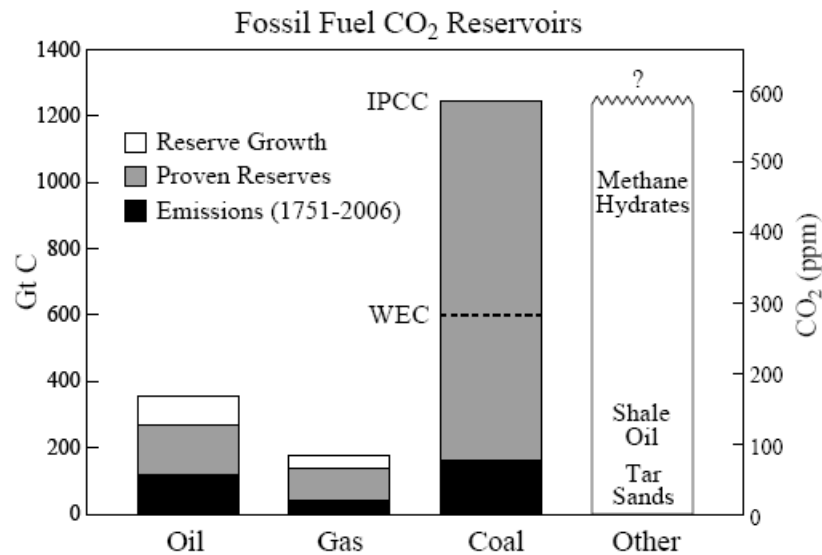


**Figure 1.** The fraction of CO<sub>2</sub> remaining in the air, after emission by fossil fuel burning, declines rapidly at first, but 1/3 remains in the air after a century and 1/5 after a millennium (*Atmos. Chem. Phys.* 7, 2287-2312, 2007).

Oil slightly exceeds coal as a source of CO<sub>2</sub> emissions today, as shown in Figure 2a. [IPCC = Intergovernmental Panel on Climate Change; WEC = World Energy Council] But, because of the long atmospheric lifetime of past emissions, fully half of the excess CO<sub>2</sub> in the air today (from fossil fuels), relative to pre-industrial times, is from coal (Figure 2b). Moreover, coal use is now increasing, while oil production has stagnated. Oil production will peak and will be constrained by available resources earlier than will coal production.



**Figure 2.** Percent contributions of different fossil fuels to 2006 CO<sub>2</sub> emissions (left side) and contributions to the excess CO<sub>2</sub> in the air today relative to pre-industrial CO<sub>2</sub> amount (CDIAC data for 1751-2004, BP for 2005-6; cf. *Atmos. Chem. Phys.* 7, 2287-2312, 2007).



**Figure 3. Estimated fossil fuel reserves; purple portions have already been used (Atmos. Chem. Phys. 7, 2287-2312, 2007).**

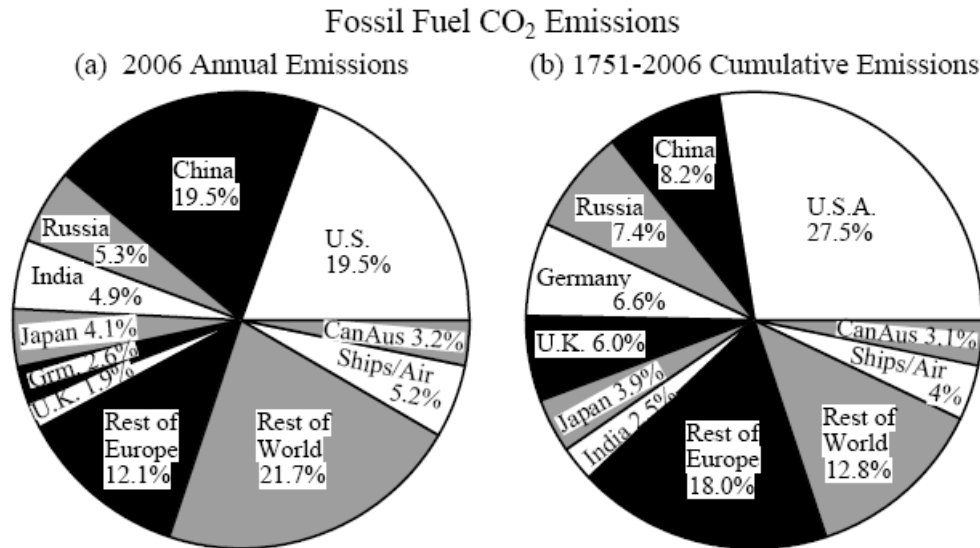
Figure 3 shows reported fossil fuel reserves and resources (estimated undiscovered deposits). Reserves are hotly debated and may be exaggerated, but we know that enough oil and gas remain to take global warming close to, if not into, the realm of dangerous climate effects. Coal and unconventional fossil fuels such as tar shale contain enough carbon to produce a vastly different planet, a more dangerous and desolate planet, from the one on which civilization developed, a planet without Arctic sea ice, with crumbling ice sheets that ensure sea level catastrophes for our children and grandchildren, with shifting climate zones that cause great hardship for the world's poor and drive countless species to extinction, and with intensified hydrologic extremes that cause increased drought and wildfires but also stronger rain, floods, and storms.

Oil and coal uses differ fundamentally. Oil is burned primarily in small sources, in vehicles where it is impractical to capture the CO<sub>2</sub> emissions. Available oil reserves will be exploited eventually, regardless of efficiency standards on vehicles, and the CO<sub>2</sub> will be emitted to the atmosphere. The climate effect of oil is nearly independent of how fast we burn the oil, because much of the CO<sub>2</sub> remains in the air for centuries. [It is nevertheless important to improve efficiency of oil use, because that buys us time to develop technologies and fuels for the post-oil era, and high efficiency surely will be needed in the post-oil era.] However, the point is this: oil will not determine future climate change. Coal will.

Avoiding dangerous atmospheric CO<sub>2</sub> levels requires curtailment of CO<sub>2</sub> emissions from coal. Atmospheric CO<sub>2</sub> can be stabilized by phasing out coal use except where the CO<sub>2</sub> is captured and sequestered, as is feasible at power plants. Indeed, agreement to phase out coal use except where the CO<sub>2</sub> is captured is 80% of the solution to the global warming crisis. Of course, it is a tall order, as coal is now the world's largest source of electrical energy. Over the next few decades those coal plants must be closed or made to capture their CO<sub>2</sub> emissions. Yet it is a doable task. Compare that task, for example, with the efforts and sacrifices that went into World War II.

## Responsibility for Global Warming

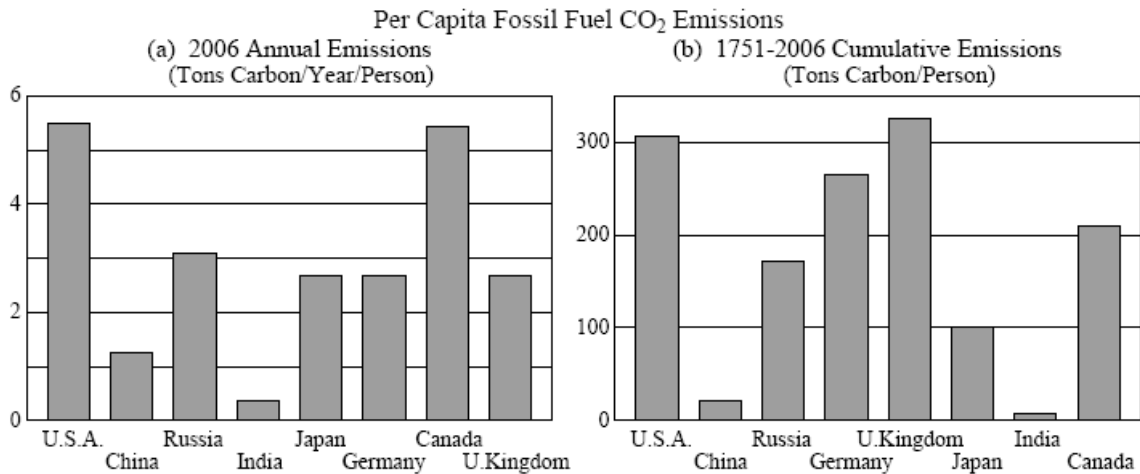
Responsibility for global warming is proportional to cumulative CO<sub>2</sub> emissions, not to current emission rates ([http://pubs.giss.nasa.gov/docs/2007/2007\\_Hansen\\_et\\_al\\_1.pdf](http://pubs.giss.nasa.gov/docs/2007/2007_Hansen_et_al_1.pdf)). This is physical fact, not an ethical statement. It is a consequence of the long lifetime of atmospheric CO<sub>2</sub>. Responsibility of the United States is more than three times larger than that of any other nation (Figure 4). Despite rapid growth of emissions from China, the United States will continue to be the nation most responsible for climate change for at least the next few decades.



**Figure 4.** Annual and cumulative fossil fuel CO<sub>2</sub> emissions by country of emission (CDIAC data for 1751-2004, BP for 2005-6; cf. *Atmos. Chem. Phys.* 7, 2287-2312, 2007).

It is also useful to examine per capita fossil fuel CO<sub>2</sub> emissions. Figure 5a shows per capita emissions for the eight nations with largest total emissions, in order of decreasing total emissions. The United States and Canada have the largest per capita emissions, while emissions of Japan, Germany and the United Kingdom are half as large per capita.

Per capita responsibility for climate change, however, must be based on cumulative national emissions. The United Kingdom has the highest cumulative emissions per capita (2006 population), as shown in Figure 5b. The United States is second in per capita emissions and Germany is third. Increased per capita responsibility of the United Kingdom and Germany is a consequence of their early entries into the industrial era. Recognition of these facts is not an attempt to cast blame. Early emissions of CO<sub>2</sub> occurred before the climate problem was recognized and well before it was proven. Yet these facts are worth bearing in mind.



**Figure 5. Per capita fossil fuel emissions (a) in order of national emissions today, (b) per capita cumulative emission (2006 population) in order of national cumulative emissions (CDIAC data for 1751-2004, BP for 2005-6; cf. *Atmos. Chem. Phys.* 7, 2287-2312, 2007).**

### **Implications**

Human-made climate change is unambiguously underway. Yet the urgency of the situation is not readily apparent to everybody. Chaotic weather fluctuations mask climate trends, even as climate change alters the nature of weather. Urgency is created by the very inertia of the climate system that delays the effects of gases already added to the air. This delay means that there is additional global warming “in the pipeline” due to human-produced gases already in the air.

Climate system inertia is due in part to the massive oceans, four kilometers deep on average, which are slow to warm in response to increasing greenhouse gases. The effect of this inertia is compounded by positive (amplifying) feedbacks, such as melting of ice and snow, which increases absorption of sunlight, engendering more melting. Such feedbacks are not “runaway” processes, but they make climate sensitive to even moderate climate forcings. [A climate forcing, natural or human-made, is an imposed perturbation of the planet’s energy balance. Examples include a change of the sun’s brightness or an increase of long-lived greenhouse gases, which trap the Earth’s heat radiation.]

Climate inertia and positive feedbacks together create the danger of passing climate “tipping points”. A tipping point exists when the climate reaches a point such that no additional forcing is needed to instigate large, relatively rapid climate change and impacts. Impacts of these large climate changes tend to be, overall, detrimental to humans, because civilization is adapted to the relatively stable interglacial period that has existed on our planet for about ten thousand years, and we have settled the land and built great infrastructure within and upon these relatively stable climate zones and coastlines.

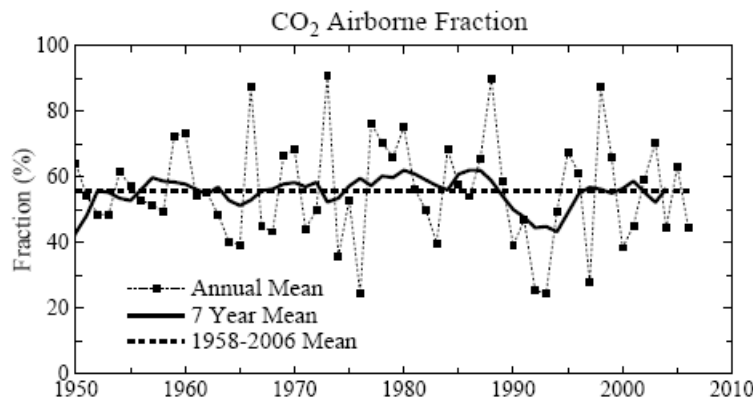
Based on current information, we now realize that we have passed or are on the verge of passing several tipping points that pose grave risks for humanity and especially for a large fraction of our fellow species on the planet. This information is gleaned primarily from the Earth’s history and ongoing global observations of rapid climate changes, and to a lesser extent from climate models that help us interpret observed changes.

Potential consequences of passing these tipping points include (1) loss of warm season sea ice in the Arctic and thus increased stress on many polar species, possibly leading to extinctions, (2) increasing rates of disintegration of the West Antarctic and Greenland ice sheets, and thus more rapidly rising sea levels in coming decades, (3) expansion of subtropical climates adversely affecting water availability and human livability in regions such as the American West, the Mediterranean, and large areas in Africa and Australia, (4) reduction of alpine snowpack and water run-off that provides fresh water supplies for hundreds of millions of people in many regions around the world, and (5) increased intensity of the extremes of the hydrologic cycle, including more intense droughts and forest fires, on the one hand, but also heavier rains and greater floods, as well as stronger storms driven by latent heat, including tropical storms, tornados and thunderstorms.

The nearness of these climate tipping points is no cause for despair. On the contrary, the actions that are needed to avert the tipping point problems are not only feasible, they have side benefits that point to a brighter future for life on the planet, with cleaner air and cleaner water. It will be necessary to roll back the airborne amounts of several air pollutants, but that is plausible, given appropriate attention. Already all pollutants except CO<sub>2</sub> are falling at or below the lowest IPCC (Intergovernmental Panel on Climate Change) scenarios, and there is much potential for further reductions.

The tendency of the media to continually report bad news on climate change and the human-made factors that drive climate change sometimes paints a picture that is bleaker than that shown by careful analysis. Such information is often misleading about the true status of the Earth, and the impression created may be harmful if it leads to despair about the prospects for achieving a relatively stable climate with a cleaner atmosphere and ocean. I illustrate with data for CO<sub>2</sub>, the most important climate forcing.

Figure 6 is the “airborne.fraction” of fossil fuel CO<sub>2</sub> emissions. This is the ratio: the annual increase of CO<sub>2</sub> that appears in the Earth’s atmosphere (well measured) divided by the annual human emission of fossil fuel CO<sub>2</sub> into the air (also well known). On average, the increase of CO<sub>2</sub> in the air is 57% of the fossil fuel emissions. Although this is a large amount, the 43% taken up by the ocean, soil and biosphere is also large. The uptake is large despite the fact that humans are also causing extensive, mostly unwise, deforestation, which adds CO<sub>2</sub> to the air. In addition our agricultural practices typically do not encourage storage of carbon in the soil.



**Figure 6. Ratio of observed atmospheric CO<sub>2</sub> increase to fossil fuel CO<sub>2</sub> emissions (*Proc. Natl. Acad. Sci.* 101, 16109-16114, 2004).**

There is tremendous potential for reducing atmospheric CO<sub>2</sub> via reduction of deforestation, improved forestry practices, and improved agricultural practices that increase carbon storage in the soil. If governments were to encourage such practices, rather than the converse, and if coal use were phased out except where the CO<sub>2</sub> is captured, it would be possible to literally roll back the net human-made climate forcing to levels below those defining critical tipping points.

We must remember, at the same time, that the ability of the principal CO<sub>2</sub> sink, the ocean, to soak up human-made emissions is limited and slow (Figure 1). If we burn most of the available coal (Figure 3) without CO<sub>2</sub> capture, even with the lowest estimates of available coal reserves, it will be impractical if not impossible to avoid passing climate tipping points with disastrous consequences.

### **Summary: The Need for Leadership**

I am optimistic that greenhouse gas emissions can be reduced and atmospheric composition stabilized at a level avoiding disastrous climate effects. My optimism is based in part on the fact that young people are beginning to make their voices heard. They have a powerful effect on our consciences, with an ability to influence policy makers and the captains of industry.

Many individuals are beginning to recognize and appreciate the nature of the climate problem. People want to take actions and they are willing to make sacrifices. However, individual actions cannot solve the problem by themselves.

Based on fossil fuel and carbon cycle facts summarized above, we cannot continue to burn the coal reserves without CO<sub>2</sub> capture and sequestration. Solution of this problem can be achieved only via strong government leadership.

Governments must recognize the relative magnitudes of fossil fuel resources, i.e., oil, gas, coal, and unconventional fossil fuels, and they must establish policies that influence consumption in ways consistent with preservation of our climate and life on Earth. The fossil fuel facts dictate essential actions

(<http://arxiv.org/ftp/arxiv/papers/0706/0706.3720.pdf>):

(1) Phase-out of coal use that does not capture CO<sub>2</sub>. This is 80% of the solution, creating a situation in which CO<sub>2</sub> emissions are declining sharply. (Coal use will also be affected by the second essential action. Indeed, it is likely that much of the coal will be left in the ground, as economic incentives spark innovations and positive feedbacks, accelerating progress to the cleaner world beyond fossil fuels.)

(2) A gradually but continually rising price on carbon emissions. This will ensure that, as oil production inevitably declines, humanity does not behave as a desperate addict, seeking every last drop of oil in the most extreme pristine environments and squeezing oil from tar shale, coal, and other high-carbon sources that would ensure destruction of our climate and most species on the planet. Recognition by industry of a continually rising carbon price (and elimination of fossil fuel subsidies) would drive innovations in energy efficiency, renewable energies, and other energy sources that do not produce greenhouse gases.

These are the two fundamental actions that must occur if we are to roll back the net climate forcing and avoid the dangerous climate tipping points, with their foreseeable consequences. Both of these actions are essential.

We can make a long list of supplementary actions that will be needed to avoid hardships and minimize dislocations as we phase into a cleaner world beyond fossil fuels. However, the two essential actions must be given priority and governments must explain the situation to the public.

Supplementary actions include improved efficiency standards on buildings, vehicles, appliances, etc. Rules must be changed so that utilities profit by encouraging efficiency, rather than selling more energy. These changes are necessary for success, and there are many economic opportunities associated with them. Yet governments must realize the essential actions dictated by the physics of the carbon cycle. Specifically, release of CO<sub>2</sub> to the air from the large carbon reservoirs, coal and unconventional fossil fuels, must be curtailed.

Further actions will be needed to achieve a rollback of the net climate forcing. These actions (<http://arxiv.org/ftp/arxiv/papers/0706/0706.3720.pdf>) include reduction of non-CO<sub>2</sub> climate forcings and improved agricultural and forestry practices. These actions are important and have multiple benefits, especially in developing countries, but they do not have the great urgency of halting construction of new coal plants without carbon capture. Power plants have long lifetimes, and once their CO<sub>2</sub> is released to the air, it is impractical to recover it.

Energy departments, influenced by fossil fuel interests, take it as a God-given fact that we will extract all fossil fuels from the ground and burn them before we move on to other ways of producing usable energy. The public is capable of changing this course dictated by fossil fuel interests, but clear-sighted leadership is needed now if the actions are to be achieved in time.

Tipping points and positive feedbacks exist among people, as well as in the climate system. I believe that the action with the greatest potential to initiate positive feedbacks, and lead to the benefits that will accompany a clean energy future, is a moratorium in the West on new coal-fired power plants unless and until CO<sub>2</sub> capture and sequestration technology is available. Such a moratorium would provide the West with sufficient moral authority to sit down with China and other developing countries to find ways, likely including technological assistance, for developing countries to also phase out coal use that does not capture CO<sub>2</sub>.

Perhaps the most important question is this: can we find the leadership to initiate the tipping point among nations? Can we find a country that will place a moratorium on any new coal-fired power plants unless they capture and store the CO<sub>2</sub>? Unless this happens soon, there is little hope of avoiding the climate tipping points, with all that implies for life on this planet.