Europe Standing Tall Against a Rogue State

08 September 2013

James Hansen

I spent a week in May in European capitals (Brussels, the Hague, Berlin, London and Paris) discussing the role of tar sands and other unconventional fossil fuels in climate change. Mark Jaccard (Canadian professor of environmental economics) and I were invited to participate in a debate in the European Parliament, providing scientific evidence relevant to the European Fuel Quality Directive.

The basic issue of this Directive (law) that EU is discussing is whether unconventional fossil fuels should get higher GHG (greenhouse gas) values to include emissions that occur in mining and processing of the fuel. Europe has been a leader in recognizing the importance of climate change and the need to take account of emissions during the complete fuel cycle, e.g., during production of biofuels. Thus, there is wide respect for the European position, which could affect potential world-wide expanded production of carbon-intensive unconventional fossil fuels. The EU has laws requiring automobile and other industries to reduce emissions, but this is the first time that the oil industry is asked to reduce its impact on climate. Hence the importance of this Directive.

We had meetings with officials in each capital and made a few public presentations during the tour. Our public presentations were shadowed by a Canadian government lobbyist for tar sands, but he soon learned that it was better that he not interject in the discussions, because Mark and I could readily counter his misinformation.

We were heartened by the reactions in these countries and in the European Parliament. The European Commissioner for Climate Action, Connie Hedegaard, is determined to have honest accounting of emissions from all fuels. We are optimistic that Europe will stand tall in resisting backroom pressure from a Canadian government and the oil industry, which seem intent on making Canada into a rogue state.

Canada agreed to match the United States goal of reducing CO_2 emissions 17% between 2005 and 2020. However, the present Canadian government's own audit division admits that, as a result of tar sands development, their emissions are instead likely to <u>increase</u> 7-10% by 2020.

I try to make this story clearer in the following draft of a letter to my oldest grandchild. One thing I have learned is that the Canadian government's position re tar sands does not seem to be representative of Canadians in general. Supportive messages that I receive from Canadians outnumber criticisms by about ten-to-one. People in Alberta, the oil province, were friendly when I went there in 2010 to testify against tar sands.

If Europe labels tar sands appropriately and the U. S. rejects the Keystone XL pipeline, expansion of tar sands development will be blocked temporarily and the oil industry will need to rethink its strategy of investing in highly GHG intensive fossil fuels. If a rising carbon fee is adopted in the next few years the infrastructure for that unconventional oil will never be needed. The economically sensible fee-and-dividend approach would result in millions of jobs as we move toward a clean energy future.

Upcoming decisions of political leaders have great implications for the future of young people and nature. If political leaders cave in to backroom pressure from the multinational fossil fuel industry, no explanation can succeed in cloaking their lack of moral courage in facing the demands of that industry.

We stand at a unique point in history when it is still possible to minimize climate disruption via an honest rising fee on carbon emissions that makes fossil fuels pay their costs to society, thus spurring our economies and a transformation to clean energies. If, instead, we choose to appease the fossil industry, subsidizing a move into unconventional fossil fuels, history and our children will surely recognize our connivance and cowardice and may judge us no less harshly than the judgment rendered upon the pre-war appeasers of the 1930s.

Tar Sands Debacle and the Hama-Hama-Hama Oil and Gas Corporation

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Dear Sophie,

Did you know that the film "Avatar" has a relation to the tar sands development in Canada?

James Cameron, the writer and director of Avatar, visited the huge tracts of once-forest land in Canada that are being, let's say, "worked on" by oil companies. Giant bulldozers scrape off forest cover to get at a layer of tar-like goop called bitumen. Photos here give an idea of what Cameron saw.

A piece of the tar sands operations in Canada.

Pristine forest is replaced by a ghoulish scene.

Tar sands goop, a.k.a. bitumen.

Goop carrier; man (in lower right) is 6' tall.

Tar sands goop on the move.

Preliminary processing of goop is done on site...

…with waste dumped into large lagoons.

Bird stopped for a drink - his last - won't live long.

Tar sands workers: good jobs, huh?

One of the mammals joining the Avatar in battle against the mining company.

Avatar

The Avatar story involved destructive mining in the 22nd century on the moon Pandora in the Alpha Centauri star system. The mining company's headquarters were located on Earth. Their objective was extraction of a rare precious metal, unobtanium. The richest deposit was located under sacred grounds of the Na'vi natives of Pandora, 10-foot (3 meters) tall, blue-skinned humanoids, who lived in harmony with nature.

One of the humans involved in the Pandora operation was a paraplegic ex-Marine, whose mind could be electronically linked to a Na'vi host body. This Na'vi-human hybrid (an 'Avatar') was supposed to infiltrate the Na'vi people and help eliminate resistance to the mining operation.

The Na'vi refused to evacuate their sacred gathering place, whereupon the mining company headquarters ordered that bulldozers should clear the land. The bulldozers of the mining company were backed by Earth's military including bomber aircraft. Mining companies had strong influence over government on Earth, such that their operations and the supply line between the mine and Earth's customers were protected and supported by Earth's military.

Over time the ex-Marine Avatar had begun to sympathize with the Na'vi and decided to fight alongside the Na'vi against the mining company. It was an unequal fight. The battle went very badly for the Na'vi. They suffered heavy casualties, as they were overmatched by the military from Earth. But then large Pandoran animals, a motley array of wildlife, unexpectedly joined the fight and decisively turned the tide against the mining company and its military support.

Sophie, although the blue-skinned Na'vi on Pandora are science fiction, the Avatar story is actually happening on our planet now. Native Americans are Na'vi. First Nation people of Canada are Na'vi. We are Na'vi -- all people who love nature and the life on our planet are Na'vi.

However, I am jumping ahead too fast. We need to first understand tar sands -- what they are and why they are useful. Tar sands are one of the "fossil fuels." Fossil fuels provide most of our energy, the energy that moves our automobiles, provides our electricity, heats our homes, and powers our industries. Let's talk about fossil fuels in general, then specifically tar sands.

Woodmobile of World War II vintage and a slightly more modern version.

Fossil Fuels

Ordinary fossil fuels, called "conventional" fossil fuels, are oil, gas and coal. Oil, gas and coal are almost "ready to use" when found in the ground at various places around the world. Oil, however, is refined into different petroleum products, so the resulting gasoline (or "petrol") will burn cleanly, thus enhancing the efficiency and lifetime of engines.

Unconventional fossil fuels, such as tar sands, are usually difficult to extract from the ground and are in a less pure condition than conventional fuels. Substantial energy is needed to extract and purify an unconventional fuel before it is ready to be used. Therefore, unconventional fossil fuels yield a more costly energy product. Also, the mining and processing of unconventional fuels can cause greater environmental destruction.

All fossil fuels are a form of stored energy -- concentrated energy of sunlight stored in plants and microbes (microscopic organisms) that grew millions of years ago. Plant leaves absorb sunlight, using the sun's energy to make sugars and starches, which plants use in turn to make structural material such as the cellulose fibers in wood.

Why do we go to the trouble of digging up the remains of things that grew millions of years ago? Can't we get the stored energy by burning leaves and wood of plants growing today? Indeed, wood was our main energy source for centuries. We could use wood to fuel automobiles.

During World War II, when oil was in short supply, there were half a million "woodmobiles," mainly in Europe, such as shown in the above figure. Engines in woodmobiles are nearly the same as in a normal automobile, but they need a "wood gasification" unit to make gas out of wood. Apparently, the gasification unit makes the vehicle bigger or reduces its trunk space a bit. One problem with woodmobiles was that they could only go about 100 km (60 miles) on a load of wood. Then the driver had to either find another woodpile or carry an axe and get to work.

Fossil fuels are much more convenient than wood, partly because they have a higher energy density. How does that come to be? Most fossil fuels are formed from plants that grew during the Carboniferous Period, which lasted from about 360 million years ago to 300 million years ago. Large areas of land were covered by swamps, with huge trees, ferns, and leafy plants, and the water was filled with algae. Algae are tiny plants, microbes, that form the green stuff you find on a stagnant pool of water.

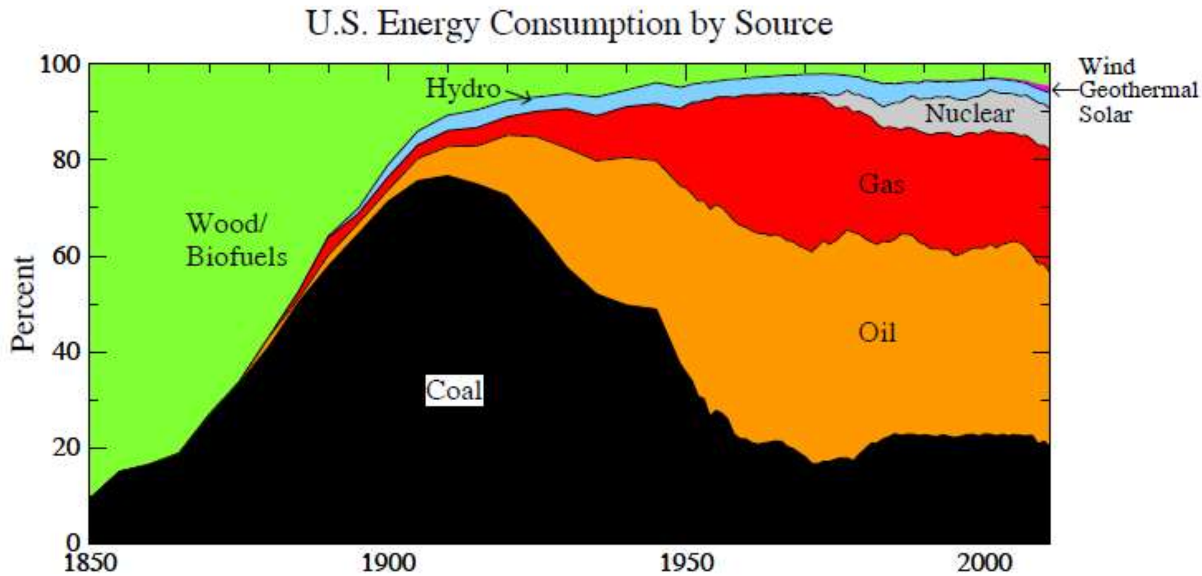

Fig. 1. United States energy consumption.

When plants died and sank to the bottom of the swamp, they formed thick layers of spongy material called peat. In some places these peat layers were eventually covered by layers of sediments -- sand and mud -- either because the swampy area became a lake or because sea level rose and shallow ocean covered the swampy area. Over millions of years the layers of sand or mud sediment could become so thick that the sediments at great depth were compressed into stone -- "sedimentary rocks" called sandstone and mudstone.

I will show you some examples of sandstone and mudstone in the huge pile of stones that I have collected on the concrete platform across the driveway from our house. The mudstones are usually called shale. The big gray flat stones in my rock pile are shale (those are the stones I will use to make a wall around our patio -- Oma is despairing whether I will ever get to it!).

So what happened to the peat? The heavy weight of sediments and sedimentary stone above the peat caused high pressure and temperature that compacted and transformed the peat into coal. Other fossil fuels, oil and gas, are formed in the same way. The resulting type of fossil fuel depends on the plant (and, to a much less extent, animal) material that accumulated under the swamp or other water body and on the history of how it was compressed and heated. Buried terrestrial plants usually yield coal and gas, while buried algae can yield oil and gas.

Fossil fuels replaced wood as the world's main source of energy because of the high energy density of fossil fuels, the ease with which they can be transported and used, and their low cost. It was easy to get large amounts of the fuels out of big fuel reservoirs near Earth's surface.

Coal supplanted wood and fueled the industrial revolution in the 19th century. Oil and gas use grew rapidly in the 20th century. The history of fossil fuel use in the United States, shown in the above graph, is reasonably similar to the history for the whole world, except that coal still provides about 30% of world energy but only 20% in the United States. Fossil fuels provide most of our energy today.

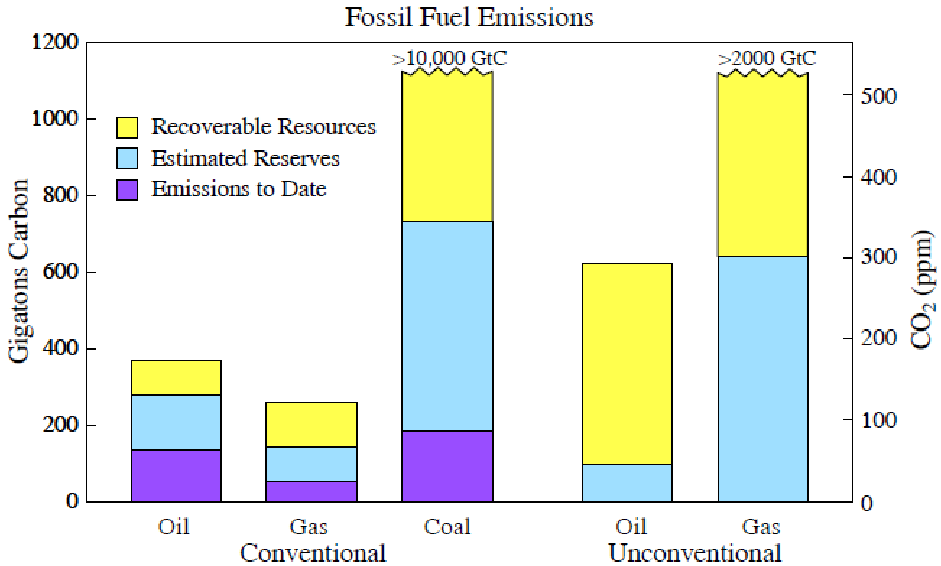

Fig. 2. CO_2 emissions from fossil fuels. Purple is amount emitted so far. Blue is fuel in known economically-extractable reserves. Yellow is further amount expected to become economically extractable as prices rise and technology improves. Fossil fuel emissions through 2012 are 370 GtC [1 ppm CO_2 ~ 2.12 GtC; ppm = parts per million; GtC = gigatons carbon; gigaton = 1 billion tons].

Carbon Dioxide (CO_2) Emissions

We have used only a fraction of the fossil fuels in the ground, the purple piece in the chart above. The total amount of carbon in the fossil fuels we have burned so far is 370 billion tons, which is written as 370 GtC, which is read as 370 gigatons carbon. A gigaton is a billion tons.

Let me mention just a few other simple facts, which will allow you to understand numbers that people use. It will help make you expert enough to understand discussions about fossil fuels.

First, the mass given in the above chart is the mass of carbon in the fuel. When the fuel is burned the burning process combines each carbon (C) atom in the fuel with an oxygen molecule (O_2). As you will learn in a chemistry or physics class, the mass of a C atom is 12 on a relative scale that defines mass = 1 to hydrogen (H), the lightest atom. Oxygen (O) has mass 16. So the mass of CO_2 is (12 + 16 +16). Thus burning 1 GtC of fossil fuels yields 44/12 gigatons of CO_2 in the air, which is about 3.7 gigatons of CO_2, written as 3.7 $GtCO_2$.

Second, humans are also adding CO_2 to the air by cutting down forests and burning the wood. In some places the forests are regrowing, thus taking the CO_2 back out of the atmosphere. So it is difficult to accurately specify the net input of CO_2 into the atmosphere from all of the ways that humans have altered the vegetation on Earth's surface. Current estimates for this net input are about 100 GtC. Thus, the total human-made CO_2 emission is about 370 + 100 = 470 GtC.

It is useful to keep our carbon "bookkeeping" for fossil fuels and deforestation separate, because these two carbon sources are fundamentally different. For the moment, I just mention one major reason for this. The CO_2 put into the air by deforestation potentially can be put back into forests and into the soil this century by means of improved forestry and agricultural practices. Indeed, it is probably necessary to do that to avoid dangerous climate change. I will discuss reforesting of land that is of marginal value for agriculture and improving soil management in another letter.

Earth's Energy Balance

This letter is getting a bit technical. Let's talk about it soon. The tar sands topic includes a lot of basic climate science, so once you understand it, the rest of the climate story will be duck soup.

Let's imagine we have a planet revolving around a star in a circular or nearly circular orbit. These could be our own planet, Earth, and our own star, the Sun. What do you think determines how warm the planet is? Obviously, an important factor is how close Earth is to the Sun. The Sun provides the energy to keep a planet warm.

Earth would be much colder if it were located way out in the solar system by the dwarf planet Pluto. Pluto's average temperature is about 44K. That's 44 Kelvin or 44 degrees above absolute zero.[1] 44°K is about -229°C or -380°F on the Celsius and Fahrenheit scales, i.e., it is hundreds of degrees below zero on temperature scales that the public uses. Out there Earth may not have exactly the same temperature as Pluto, because the temperature depends on how much sunlight the planet absorbs, not the amount of sunlight that hits the planet.

On a hot summer day you probably wear light-colored clothes to help keep cool. If you wore black you would absorb more sunlight and you would be hotter. The same principle applies to planets. Pluto, a rocky dwarf planet, absorbs only 40-45% of the sunlight hitting it because there is a lot of ice and snow on its surface. Rocks tend to be rather dark, but because of the ice and snow Pluto absorbs less than half of the incident sunlight.

Earth is darker than Pluto. Earth is 70% covered by ocean, which is very dark and absorbs more than 90% of incident sunlight. Much of the remaining 30% of Earth is covered by forest or other plants. Plants are also dark, absorbing most of the sunlight that hits them, because they need that sunlight to grow and to manufacture sugars and starches. The result is that Earth is rather dark, absorbing 70% of the sunlight hitting the planet. Earth would absorb even more of the sunlight except for the fact that more than half of the planet is covered by clouds. Also the polar regions have ice and snow on parts of the surface.

Given that Earth absorbs 70% of incident sunlight, what determines Earth's temperature? Earth's energy balance. Earth not only absorbs sunlight, it also radiates heat energy to space. On average, the amount of heat energy that Earth radiates must equal the amount of solar energy that Earth absorbs. We can easily prove this statement by a "gedanken" (thought) experiment. All that we need to know is that a body radiates more heat energy as its temperature increases, which is an experimental fact. Now imagine that Earth absorbed more solar energy than it radiated

[1] The Kelvin temperature scale is what physicists use. Absolute zero temperature, the zero point on the Kelvin scale, is the point at which all motion ceases; molecules even stop wiggling. That is really "stone cold", the coldest you can get. The size of a unit of the Kelvin scale is the same as for the Celsius temperature scale. Celsius is the temperature scale used by the public in most of the world. The Celsius scale is defined by taking 0°C as the temperature at which water freezes and 100°C as the temperature at which water boils and dividing that range up in 100 equal units. Celsius temperature used to be called "centigrade" because of the 100 equal units. Celsius is useful for the public because it puts everyday temperature into a useful range of small numbers. Also the conversion between Kelvin and Celsius is simple -- just add 273 to the Celsius value to get the Kelvin value (or 273.16 is you want to be precise). Unfortunately, there is one more temperature scale that you need to know. The Fahrenheit scale is used by the public in the United States and a few Caribbean islands. The Fahrenheit scale has the freezing point as 32°F and the boiling point at 212°F, so conversion to or from the Fahrenheit scale is inconvenient.

away as heat. In that case, with more energy coming in than going out, Earth's temperature will increase. How high will it rise? It must continue to rise until the heat radiated by Earth equals the amount of absorbed solar energy. Earth would then have energy balance.

This energy balance, energy in equals energy out, can be written as a mathematical equation. We can use it to calculate Earth's average radiating temperature, because we know how much sunlight Earth absorbs. I won't write the equation, but just give the answer from the equation.

Earth's average temperature must be -18°C for Earth to radiate as much energy as it absorbs. Whoa, isn't -18°C pretty cold, you might ask. Yes, -18°C is approximately 0°F. However, Earth's average surface temperature is +15°C (59°F). So, Earth's surface temperature is 33°C (almost 60°F) warmer than Earth's radiating temperature. Explanation: Earth's radiating temperature that we calculated from the energy balance equation is the average temperature of the levels in the atmosphere that radiate most of the heat that escapes from Earth to space.

The 33°C warming of the surface relative to the radiating temperature is the natural "greenhouse effect". If the atmosphere did not absorb heat radiation, the surface temperature would be -18°C, rather than +15°C. So the natural greenhouse effect is very useful. Without the greenhouse gases in Earth's atmosphere, the oceans and lakes would be frozen -- Earth would be an iceball.

The greenhouse effect is caused by gases such as CO_2 and H_2O (water vapor) that absorb heat radiation. These gases act like a blanket, trapping Earth's heat, reducing Earth' s heat radiation to space, thus keeping the surface warmer than it otherwise would be. This simple "blanket" explanation is scientifically correct and sufficient for most purposes. I give a few more details below[2] that may be useful to some people, but it is o.k. to skip this paragraph. If you take physics in college you might be interested, but otherwise maybe not.

[2] Almost all heat radiated to space by Earth emerges from the atmosphere, not the ground. Solar radiation arises from the sun's surface, which has a temperature of about 5780°C. A body at that temperature produces a spectrum of radiation mainly in the range from ultraviolet to red and near-infrared wavelengths, which is the reason we have eyes sensitive to this "visible" radiation. Earth radiating temperature is 255°K, a factor of 20 smaller than the solar temperature, so Earth's heat radiation peaks at wavelengths a factor of 20 longer than visible light, putting Earth's heat radiation in the far infrared spectral region. Gases such as CO_2 and H_2O have absorption bands in this infrared region. Absorption of infrared radiation is strong at the center of the bands, which makes the atmosphere rather opaque at those wavelengths. Therefore, most radiation to space from the band centers emerges from high in the troposphere, the convectively mixed lower atmosphere that reaches heights of about 20 km (kilometers) in the tropics and 5-10 km in polar regions. At spectral regions of weak absorption between the absorption bands the heat radiated to space arises from lower in the atmosphere and a small amount arises from the ground. On average the heat radiation emerges from a height of 5-6 km, where the temperature is about 255°K (-18°C). As the amount of CO_2 and H_2O increase the radiation emerges from a higher, colder level, reducing the heat radiation to space.

Human-Made Greenhouse Effect

Now let's consider the human-made greenhouse effect. When people talk about "global warming" they are referring to the additional warming that occurs as a result of the human-caused increase of greenhouse gases. Humans are causing several greenhouse gases to increase, the most important one being CO_2 and the next most important being methane (CH_4). For simplicity in the following discussion I will simply refer to CO_2.

An increase of CO_2 is an added blanket that reduces Earth's heat radiation to space. This added blanket causes Earth to have a temporary energy imbalance. The amount of energy that Earth is radiating to space becomes less than the solar energy that Earth is absorbing.

This planetary energy imbalance defines the most fundamental problem that climate science must solve. The problem has two parts. Specifically: (1) How much will Earth need to warm to restore energy balance? (2) How long will it take for Earth to restore balance?

This is a very simple problem. This is a very hard problem. The overall problem and its solution are constrained by simple fundamental physics. Yet some details of Earth's climate and climate change are quite complex. A scientist must be able to see both the "forest" and the "trees", the way the overall climate system works as well as detailed processes that occur within the system.

In my letter on "how science works" I emphasized how observations guide development of understanding. Climate science has the benefit of both modern global observations of the climate system during an era in which climate is changing and also paleoclimate (ancient climate) data showing how climate changed during Earth's history. In order to successfully analyze and understand the human impact on climate, in order to see the forest for the trees[3], it is essential to have good knowledge of both modern observations and paleoclimate data.

A crucial fact is that Earth responds slowly to changed atmospheric composition. This slow response has important implications. First, it makes it more difficult for people to notice that humans are altering the natural world. Second, it also raises the possibility that people living today will cause changes that mainly affect their children, grandchildren, and future generations.

We need to understand the reason for this slow response and how we can measure its effect.

I know this letter introduces a lot of physical concepts. Don't worry if you get stuck on some, just try to plow ahead. These topics will become clearer when we come back to them later.

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[3] An example of "trees" making it harder to see the "forest" is provided by a few television weather forecasters who still insist that human-made global warming, if it even exists, does not change the weather. These people expertly report development and movement of high and low pressure systems, which can alter day-to-day temperature by 10 or 20 degrees. Of course, weather systems continue to perform pretty much as they always have, so it is easy to see how some forecasters might conclude that nothing has changed. However, information from a range of sources, including basic theory showing that global warming affects weather in a statistical sense, growing modern observational data showing an increased frequency and severity of extreme events, and paleoclimate evidence for climate sensitivity to atmospheric composition change provide a broader basis for understanding.

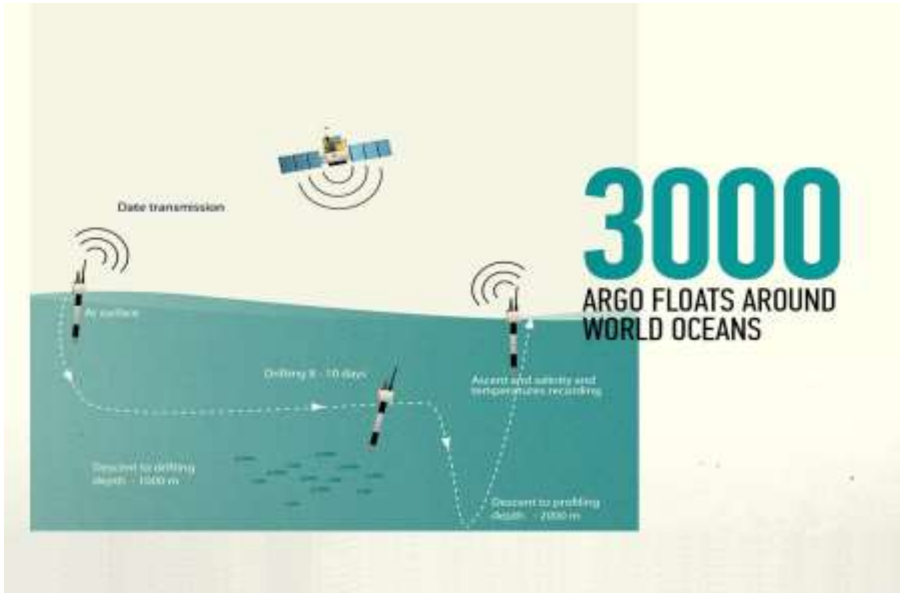

Fig. 3. Argo floats measure ocean heat content, confirming that it is increasing.

When CO_2 is added to the atmosphere Earth temporarily has an energy imbalance, more energy coming in than going out. Climate responds slowly to this energy imbalance, because Earth has great "thermal inertia". What does thermal inertia mean?

Try filling a swimming pool with cold water in mid-summer and waiting a few hours. I have not tried this, but I am quite sure you will find that the water is still pretty cold after a few hours. It likely will take at least several days for the water to warm up to a temperature consistent with the heating it receives from sunlight and the average day/night temperature of the air.

Now consider Earth's ocean. It is 4 km (about 2.5 miles) deep on average. Winds constantly churn the water, mixing it. As a result, the ocean surface requires many decades to respond fully to a change of planetary energy balance. Much of the warming for CO_2 already in the air is still "in the pipeline" -- it will occur in the future.

How can we prove this? The most basic observation is Earth's energy balance. Is more energy coming in than going out? If so, we know that there is more global warming in the pipeline.

Fortunately, beginning a decade ago several nations cooperated in deploying more than 3000 so-called Argo floats around the world oceans. The floats dive to a depth of 2 kilometers, measuring the water temperature, before resurfacing and radioing their data to a satellite. Those data reveal that the heat content of the global ocean is increasing. The ocean is the largest heat reservoir on Earth, the place where most of the heat of any planetary energy imbalance shows up.

The second largest "sink" for excess energy coming into Earth is melting of global ice. Ice is melting all around the planet, as shown dramatically in the 2012 documentary "Chasing Ice" (see trailer http://www.youtube.com/watch?v=eIZTMVNBjc4). In a given year ice may increase some places, but overall Earth's ice mass is decreasing. The biggest change is on Greenland, which is losing ice at an increasing rate. Last year Greenland lost 500 cubic kilometers of ice.

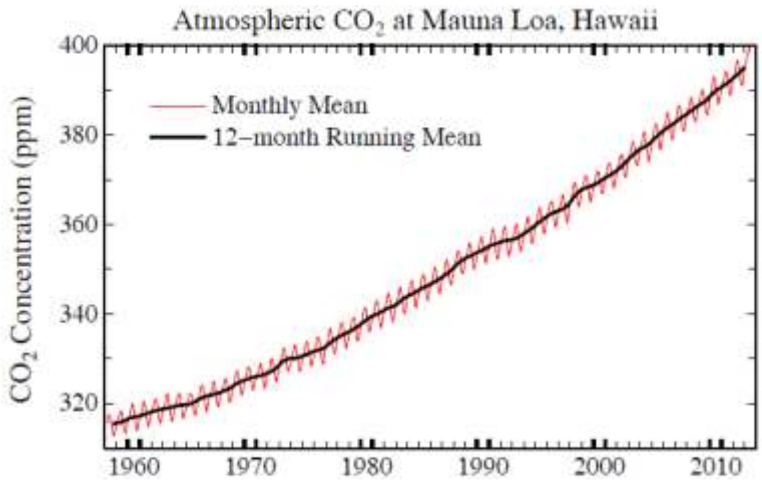

Fig. 4. Keeling curve: increasing atmospheric CO_2 as measured on Mauna Loa, Hawaii.

There are other smaller terms that contribute to Earth's energy imbalance, specifically the heat stored in the atmosphere and ground is also increasing. We have data for those terms too.

When all these terms are added up, we find that Earth is gaining energy at a substantial rate. These measurements are so important that I will discuss them specifically in another letter. Let me just mention here that the excess energy Earth is gaining, because of the planetary energy imbalance, is equivalent to exploding 400,000 Hiroshima atomic bombs per day, every day, 365 days per year. It is also 20 times greater than the total energy used by all of humanity each year. It is a significant amount of energy, and it has consequences.

Target CO_2, Target Emissions, and Target Warming[4]

Target CO_2. What is the safe level for atmospheric CO_2? The amount of CO_2 in the air today is 395[5] ppm (parts per million[6]) and it is increasing ~2 ppm per year (Fig. 4). Climate is not fully adjusted to this CO_2 level, because of ocean and ice sheet inertia. More warming will occur if CO_2 stays at 395 ppm. Present warming already has noticeable effects -- a large decrease in Arctic summer sea ice, ice sheets losing mass more and more rapidly, a global increase of extreme summer heat waves. Therefore, we should not be surprised if the scientific conclusion turns out to be that we must aim for a long-term CO_2 level less than today's 395ppm.

Knowledge of Earth's energy imbalance allows us to calculate easily and accurately how much we must reduce atmospheric CO_2 to restore Earth's energy balance and stabilize climate. By reducing CO_2 we remove some of the blanket that is warming Earth, thus letting more heat radiate to space. Calculation of the radiation to space does not require use of a climate model. It depends only on absorption and radiation of heat -- and the physics of that is well understood. The answer is that we must reduce CO_2 to about 350 ppm to restore Earth's energy balance.

[4] The quantitative basis for the targets described here is presented in a paper that is presently being published.
[5] The media reported recently that CO_2 was now 400 ppm. That was the amount measured on just a few days in Hawaii, not the global amount. Global CO_2 will reach 400 ppm in about 2 years at its present rate of increase.
[6] 1 ppm is 0.0001%, so 395 ppm is ~ 0.04%. CO_2 is a trace gas, but important -- plants need the C in CO_2 to grow.

Couldn't we instead decrease the amount of some other gases? Surely, we must try to reduce other greenhouse gases, but the potential reduction in their greenhouse effect is limited. Over the past 20 years CO_2 has been responsible for 80% of the increased greenhouse effect. In the best case, reducing other gases can slightly alleviate the required CO_2 reduction.

Barring a CO_2 reduction, the alternative to restore Earth's energy balance is "geo-engineering". The most common suggestion is to inject human-made aerosols into the stratosphere to reflect away sunlight. Such a scheme, trying to mask one pollutant with another, is a temporary band-aid, for a problem that will last millennia if large CO_2 emissions continue. And it fails to address the problem that excess CO_2 causes by making the ocean more acid, as we discuss below.
Well, you may say, we are already at 395 ppm, so isn't 350 ppm impossible? It is not physically impossible. If we stop burning fossil fuels, atmospheric CO_2 will decrease because some of the fossil fuel CO_2 we have put in the air will mix into the ocean. Also, if we improve agricultural and forestry practices, the soil and forests can take up a substantial amount of CO_2, especially if we reforest marginal land that is of little use for agricultural purposes.

Target Emissions. How much more of the fossil fuels can we burn and still stabilize climate this century? The science required to answer this question concerns the "carbon cycle," which describes how carbon is exchanged between the atmosphere, ocean, biosphere (plants and animals), soil, and rocks. I won't go into that science in detail, because scientists agree about the basic facts and the implications for climate. I will just mention a few key points.

The extra carbon we put in the air by burning fossil fuels stays in the rapidly interactive parts of the Earth system (the atmosphere, ocean, biosphere and soil) for hundreds of thousands of years before the carbon eventually goes back into the solid Earth via incorporation into rocks[7]. So for practical purposes the carbon from fossil fuel burning will be in the climate system "forever".

However, carbon put in the air by fossil fuel burning becomes distributed among the atmosphere, ocean, biosphere and soil over years, decades, and centuries. More than half of it mixes into the ocean within 100 years. Therefore, it is physically possible to have atmospheric CO_2 decrease slowly, provided that we decrease fossil fuel emissions very rapidly (several percent per year).

Additional help toward achieving an atmospheric CO_2 decrease can be obtained via a major effort to improve forestry and agricultural practices such that more carbon is stored in the biosphere (mainly in trees) and in the soil. Marginal land that is not very productive for agriculture could be reforested and extensive plowing of fields could be replaced with "minimum till" practices that help store carbon in the soil. My colleagues and I have estimated a potential of about 100 GtC, essentially replacing the historical net loss of biospheric carbon caused by deforestation. The plausibility of such a CO_2 drawdown is increased by evidence that the biosphere recently is taking up CO_2 a bit faster than expected, probably because humans are, in effect, "fertilizing" the biosphere by means of both the extra CO_2 in the air and the extra nitrogen that our pollution and agricultural fertilizers are adding to the atmosphere and waterways.

[7] Carbon is removed from the climate system via incorporation into "sea shells", the carbonate skeletons of marine life, mostly microscopic marine life, which sinks to the bottom of the ocean when the animals die, piling up in ocean sediments. Eventually these sediments are compressed into carbonate rocks, mainly limestone. It takes hundreds of thousands of years for this process to extract the carbon injected into the climate system by burning of fossil fuels.

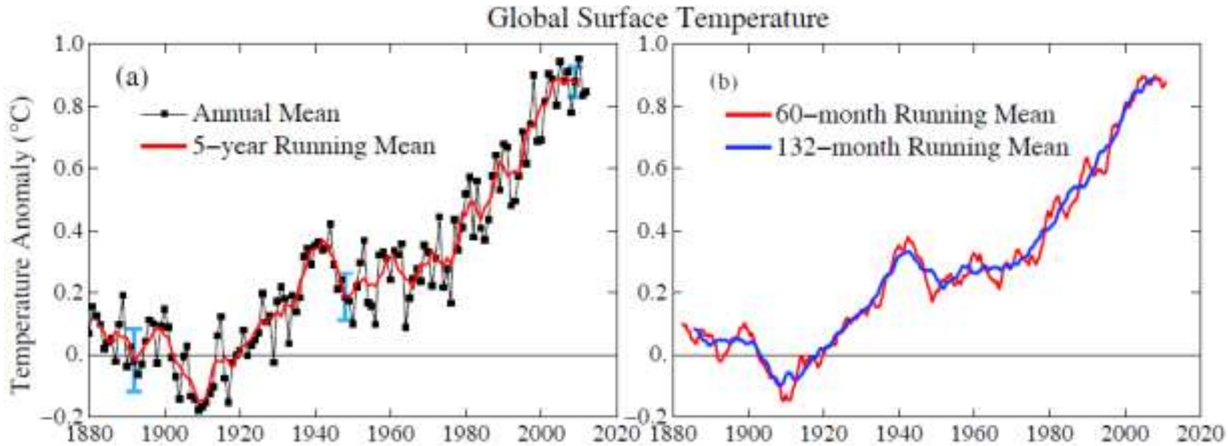

Fig. 5. Global surface temperature relative to 1880-1920 mean. (b) shows the 5 and 11 year means.

Let's make the optimistic assumption that we will pursue improved forestry and agricultural practices and achieve a 100 GtC drawdown this century. In that case, how much more fossil fuels could we burn and still achieve a reduction of CO_2 to ~ 350 ppm in 2100? Simple carbon cycle calculations yield the answer: we could burn approximately an additional 130 GtC. With the 370 GtC already burned, total fossil fuel use would be 500 GtC. Let's call this Plan A. Plan A results in CO_2 ~ 350 ppm in 2100 and global temperature about the same as today.

Below we will also discuss Plan B. Plan B has emissions 1000 GtC, compared to 500 GtC in Plan A. The reason to compare these cases will be clear after discussing global temperature.

Of course, the real world is not going to hit Plan A or Plan B on the button. Nevertheless, it is useful to consider two very specific scenarios. For people who already know a lot about Earth's history, I note that Plan A keeps global climate similar to what it has been during the Holocene, which is the past 10,000 years, a time of relatively stable climate during which all of civilization developed. Plan B would take us to planet warmer than the Eemian, which was a warm period about 120,000 years ago, and beyond to a still warmer climate. However, climate would not simply go to a new stable climate. If we follow Plan B it will be a very rough ride, because climate would not be stable again on any time scale that humanity would be concerned about.

Global Temperature Change. An alternative approach to define a limit on fossil fuel emissions is based on global temperature. This alternative approach is commonly used in international discussions, so it is useful to examine its relation with the above approach based on Earth's energy imbalance. For that purpose, we must first discuss global temperature change.

Global temperature increased ~0.8°C in the last century (Fig. 5a). Annual temperature, shown by black squares, is very "noisy", fluctuating a lot from year to year. Locally and regionally the temperature fluctuates even much more from year to year. This noisiness is a result of the fact that the atmosphere and ocean are chaotic, dynamical fluids continually sloshing about -- and the fact that the measurement refers to temperature at a single level in the system (a height in the atmosphere about ~1.5 meters (~5 feet) above the surface. We can call all of this natural variability "weather noise", although the most important fluctuations are the El Nino/La Nina oscillations in the tropical Pacific Ocean, which have time scales of years rather than days.

The 5-year (running[8]) mean temperature (red curve, Fig. 5a, 5b) partially smooths out the noise. The 11-year (132-month) mean (Fig. 5b) is still smoother. The 11-year period is chosen to minimize possible effects of the solar cycle (see below) on global temperature. The bump in global temperature around 1940 is in part a result of long-term ocean dynamical "noise" that led to the North Atlantic Ocean and the Arctic temporarily being unusually warm. The period of flat global temperature from ~1940 to ~1975 is at least in part a result of the rapid increase of fossil fuel use without pollution control during that period; increasing particulate air pollution (aerosols, i.e., fine particles in the air) had a cooling effect (by reflecting sunlight) that largely offset the warming effect of increasing CO_2. Since the 1970s air pollution controls in some nations have limited aerosol amount and the long-lived CO_2 warming has become dominant.

The past 15 years (1998-2012) are of interest, because of the assertion repeatedly made in the media that "global warming stopped in 1998". That assertion is not correct, but Fig. 5a shows the basis for that impression. The temperature in 1998 jumped far above the trend line as a result of the "El Nino of the century", a natural oscillation of Pacific Ocean surface temperature. Subsequently global temperature reached a higher level in 2005 and a still higher level in 2010, which is the warmest year in the period of instrumental measurements.

Measurements of Earth's energy balance over the last decade, discussed above, reveal an ongoing large planetary energy imbalance, more energy coming in than going out. Thus, it is nonsensical to say "global warming has stopped." The heat content of the climate system is continuing to increase rapidly. Absence of short-term warming at a specific level is not surprising. Because of the large energy imbalance, we know global warming is continuing and future surface temperature will increase.

There is a slowdown in the warming rate of the surface air, as can be seen in the 5-year and 11-year running mean global temperature. This slowdown could be partly a result of the changing brightness of the Sun. Our Sun is a variable star and some people assert that the Sun's variability is the principal cause of climate change. So, it is useful to briefly discuss the Sun's variability.

Our Sun's Brightness. Solar irradiance (solar energy crossing a unit area oriented perpendicular to the Earth-Sun direction) began to be measured in the late 1970s from space, which avoids variable interference by Earth's atmosphere. The irradiance (Fig. 6A) is found to vary by about 0.1%, with the variation coinciding with the sunspot cycle. The Sunspot Number (Fig. 6B) is a measure of the number and size of dark spots on the Sun. Solar irradiance is less in the most recent solar cycle than in prior ones, but the change is small and differs among three instruments, so the magnitude of the recent irradiance decrease is uncertain.

To find the average amount of solar energy absorbed per unit surface area of Earth we must multiply solar irradiance by 0.7 (because 30% of incident solar light is reflected away by Earth) and divide by four (because the solar energy is distributed over the surface of the planet, which is four times larger than the cross section of the planet[9]). Result: Earth absorbs about 240 watts per square meter, written 240 W/m^2. Therefore, the measured solar cycle variability (~0.1%) is a variation from maximum to minimum of about one-quarter W/m^2 (~0.25 W/m^2).

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[8] The 5-year running mean is the average for years 1-5, 2-6, 3-7, etc.

[9] Area of Earth's cross section is πR^2, where R is Earth's radius. Area of Earth's surface is $4\pi R^2$.

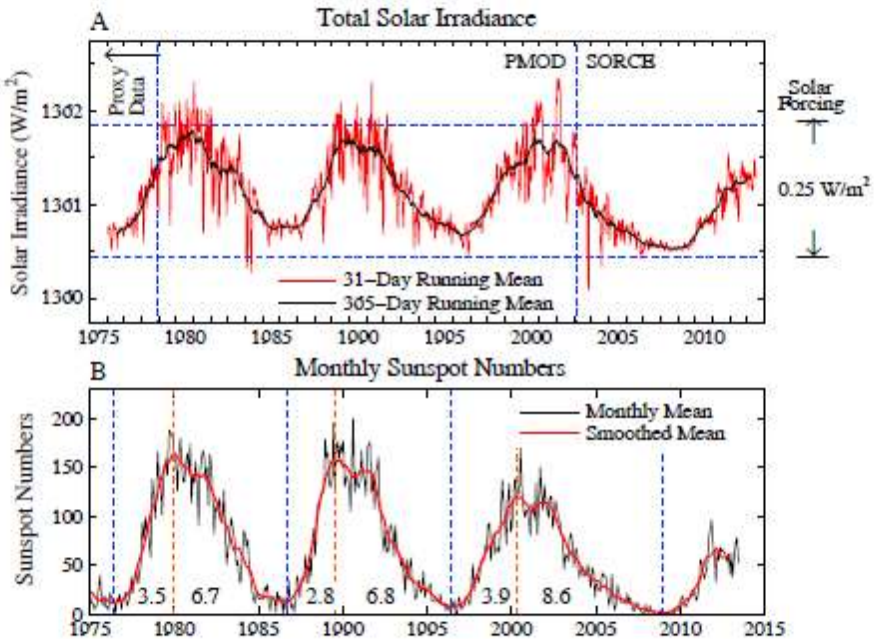

Fig. 6. Solar irradiance in the era of satellite data (A) and corresponding sunspot numbers (B).

Precise measurements of Earth's energy imbalance, described above, revealed that during the 2005-2010 period of minimum solar irradiance, incoming solar energy exceeded outgoing heat radiation by about 0.58 W/m^2, with that much more energy coming into the planet than going out. This excess of incoming energy occurred despite the fact that incoming solar energy was about 0.1 W/m^2 less than the long-term average incoming solar energy.

The important point to understand is that global warming is driven by Earth's energy imbalance. Temperature of Earth's surface is noisy; it fluctuates for a lot of reasons. However, as long as Earth's energy balance is positive (more energy coming in than going out) we know that global warming is continuing. The Sun is one of the factors that alters Earth's energy balance. It is a significant factor, but its variations are smaller than Earth's current and recent energy imbalance.

About five years ago, when sunspots were entirely absent, I received several messages, some in quite nasty language, from people who declared that human-caused global warming was in the process of being proven to be nonsense, that the Sun actually controlled climate, that the Sun was going into a long decline, and that I should commit hara-kiri or something similar. Usually these messages were accompanied by a graph of recent global temperature change showing a sharp decline and by a suggestion that Earth was headed into Little Ice Age cooling. Indeed, in 2008 it was possible to take global temperature data covering a few years and find a strong decline in temperature, because 2008 had a very strong La Nina, the cold phase of the tropical Pacific oscillation. However, even over the period of the deep solar minimum Earth's energy imbalance was positive, more energy coming in than going out, so global warming had to be continuing; the cool surface temperature anomaly in 2008 was mainly a surface manifestation of upwelling cool ocean water in the tropical Pacific. Two years later, 2010 was the warmest year in the period of instrumental records. It must have been a rude awakening from the people who were planning to publicly embarrass me if I did not commit hara-kiri. I haven't heard from them recently.

Incidentally, because of Earth's energy imbalance we will likely have a new global temperature record when the next El Nino occurs. The tropical Pacific has been in either near-neutral or in the cool phase for five years, which makes an El Nino highly likely within the next 1-2 years. 2013 is not going to have a record global temperature, but there is a good chance that 2014 will have the highest global temperature in the period of instrumental measurements

This brief diversion to compare solar variability and Earth's energy imbalance has exposed so much of the fundamental physics that I cannot resist the temptation to take it one step further. I realize that the above already may be more than you are comfortable with, but here is an inducement. Once you grasp the above physics and this one additional concept, you will be equipped to have greater insight into global climate change than 99 of 100 college educated adults, including educated adults who are particularly interested in climate change.

Well, actually …. there will still be one more item to be introduced later …. it is called "slow feedbacks" …. sounds ominous, and in one sense it is …. but we can save that topic for later.

Climate Forcings. Do you remember when Connor was a baby and we had you hold up two tiny one-watt light bulbs, and Connor supposedly could only count one watt? I was preparing for what I thought was an important talk, as I described in my book, "Storms." I was trying to find a way for people to have a feeling for the human-made "climate forcing."

A climate forcing is the planetary energy imbalance caused by an imposed change to the planet. The amount of CO_2 in the air in 1900, by which time humans had burned only little fossil fuels, was about 295 ppm. Today CO_2 is at 395 ppm. That increase of CO_2 from 295 to 395 ppm, if it occurred instantly with Earth's temperature fixed at its 1900 value, would reduce Earth's heat radiation to space by ~1.7 W/m^2. However, humans are doing things that make the net forcing bigger (adding other gases such as methane) and other things that make the net forcing smaller (increasing atmospheric aerosols). So, I wanted to illustrate that we were not certain whether the human-made forcing was closer to 2 W/m^2 or 1 W/m^2.

There is a large amount of research suggesting that the changes of other human-made climate forcings, besides CO_2, substantially offset each other for the past century as a whole.[10] Therefore the CO_2 change provides a useful approximation of the entire human-made climate forcing. However, the change from 295 to 395 ppm did not occur all at once. CO_2 actually increased slowly over the past century, which allowed Earth enough time to partially warm up in response to the forcing. The present energy imbalance, ~0.6 W/m^2, is the residual forcing that remains. In other words, the 0.6 W/m^2 is the portion of the 1.7 W/m^2 that Earth has not yet responded to.[11]

Now let's do an interesting check. Earth's climate history, so-called paleoclimate or ancient climate, provides empirical information on how sensitive Earth's global temperature is to a

[10] They didn't balance at each point. Rapid increase of fossil fuel use after World War II caused rapid increase of aerosols and then a leveling off with pollution controls, while long-lived CO_2 accumulated more steadily over time.
[11] It gets just a bit more complicated when we consider the effect of slow feedbacks.

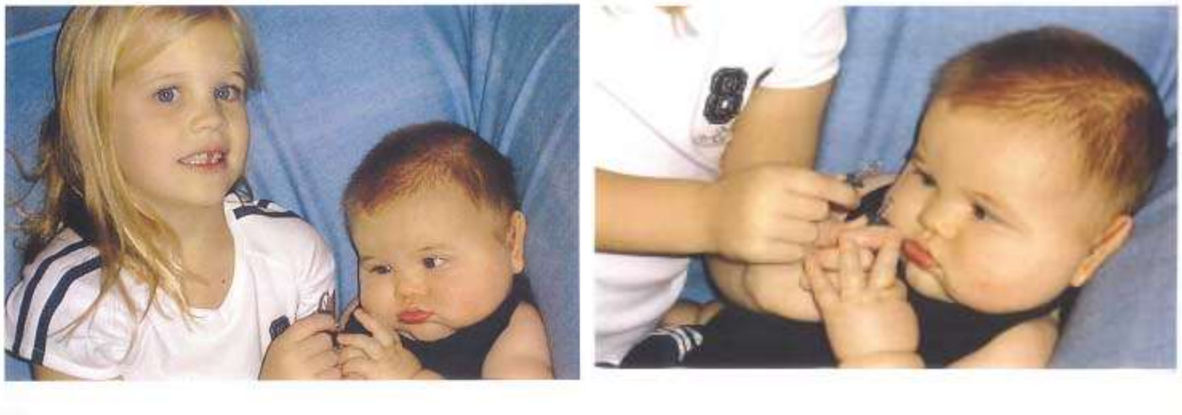

Fig. 7. From "Storms of My Grandchildren": Granddaughter Sophie explains to baby brother Connor that the net climate forcing is equivalent to two 1-watt light bulbs over every square meter of Earth's surface. Connor, however, counts only one watt.

climate forcing. Paleoclimate history indicates that the eventual climate response[12] is about 0.75°C for each watt of climate forcing. So the observed warming of ~0.8°C has "used up" a bit more than 1 W/m^2 forcing -- to be precise 0.8/0.75 ~ 1.07 W/m^2. Therefore the remaining forcing (the planetary energy imbalance) should be about $1.7 - 1.07 = 0.63$ W/m^2. The close agreement of the expected imbalance (0.63 W/m^2) and the observed imbalance (0.58 W/m^2) is partly accidental because of various uncertainties. The biggest uncertainty is caused by our inclusion of only the CO_2 climate forcing, which is based on our estimate that the positive forcing due to other greenhouse gases such as methane approximately balances the negative forcing caused by human-made aerosols. Nevertheless, it is a significant check in the sense that it explains why we should expect an energy imbalance of roughly the observed value.

O.K., now we are ready to proceed to Target Global Warming.

Target Global Warming. Our 350 ppm CO_2 target and 500 GtC emissions target were derived from the most fundamental physics of the problem, Earth's energy imbalance, which is the direct consequence of increasing CO_2. To restore Earth's energy balance, as needed to stabilize climate, CO_2 must be reduced to ~350 ppm, and thus fossil fuel emissions must be limited to ~500 GtC.

An alternative approach to obtain an emissions limit is via a target for allowable global warming. This alternative approach has been employed in international discussions. Specifically, a global warming limit of 2°C (3.6°F) has been widely accepted[13]. The 2°C target leads to estimates for an emissions limit closer to 1000 GtC, rather than the 500 GtC that we estimated.

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[12] The eventual global warming in response to the forcing is called the equilibrium climate response, because it is the temperature change after a sufficient time for the planet's energy imbalance to become ~0. However, an imbalance ~0 may be only a "quasi-equilibrium," if there is reason to expect slow feedbacks are out of balance.

[13] The European Union in 1996 proposed to limit global warming to 2°C relative to pre-industrial times. The 2°C target was reaffirmed in the 2009 "Copenhagen Accord" emerging from the 15th Conference of the Parties of the United Nations Framework Convention on Climate Change, with specific language "We agree that deep cuts in global emissions are required according to science, as documented in the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius…".

It is crucial for the public to know now which of these targets is more appropriate. Achievement of anything close to 500 GtC requires rapid policy changes. If it is correct that the target needs to be ~500 GtC, but the world believes a ~1000 GtC target is adequate, that latter belief may lead to energy infrastructure that makes 1000 GtC fossil fuel emissions practically inevitable.

My colleagues and I have concluded that the 1000 GtC fossil fuel emissions target would be disastrous for life on this planet. We have written a paper, "Scientific Prescription to Avoid Dangerous Climate Change to Protect Young People, Future Generations, and Nature," in which we explain that 500 GtC and 1000 GtC emissions are fundamentally different. With 500 GtC emissions we can retain a climate comparable to that which has existed for the last 10,000 years, thus a planet similar to that on which civilization developed. In contrast, 1000 GtC would set in motion continual changes, creating a situation that may be out of control of future generations, with consequences for other life on the planet as well as the economic well being of humans.

We have had difficulty in publishing this paper, not because of the science, which received the highest evaluations, but because of what editors and editorial boards describe as "normative" statements in the paper. We insist on pointing out clearly the implications of the science and the intergenerational injustice of continued growth of fossil fuel emissions, as well as the failure of governments to do their job of protecting the rights of all people, including young people.

The greatest difficulty, however, is in persuading even those people who are concerned about climate change that there is such a great difference in the consequences of 500 GtC and 1000 GtC emissions. That difficulty in turn is related to the supposed association of 500 and 1000 GtC with 1°C and 2°C global warming, which makes it sound like it is just a matter of degree. How much difference can a degree make -- can't we adjust to another degree Celsius?

Slow Feedbacks. Part of the explanation of why 500 GtC and 1000 GtC targets are so different is that 1000 GtC will not really yield 2°C global warming. Climate models used to associate 1000 GtC with 2°C do not include all "slow feedbacks". Earth's history reveals that climate change induces other Earth system changes. These feedbacks can either amplify or diminish the initial climate change, but it turns out that the dominant feedbacks on time scales of decades, centuries and millennia are amplifying ones. These feedbacks are best explained by examples.

Feedback 1: Forests and other vegetation move toward higher latitudes and higher altitudes as the planet becomes warmer, especially in North America and Eurasia. High albedo (reflectivity) surfaces such as tundra are replaced by darker vegetation, which absorbs more sunlight and amplifies the warming. ***Feedback 2:*** Ice sheets, including Greenland and fringes of Antarctica, would begin to melt and recede, exposing darker ground that would eventually be vegetated. Even while the ice sheet is still present, larger portions of it would be wet in the summer, making the ice darker, absorbing more sunlight. ***Feedback 3:*** The climate produced by 1000 GtC would cause increases of the amounts of trace gases such as CH_4 and N_2O. It is even conceivable that warming could melt methane hydrates[14], releasing very large quantities of CH_4. However, even in the absence of such catastrophic methane release, the paleoclimate record shows

[14] These are structures in which methane gas is trapped in ice "cages". They are most commonly found deep below the seafloor on continental margins and below permafrost soil on land. They contain vast quantities of methane.

unambiguously that a warmer climate will result in higher amounts of CH_4 and N_2O in the air, with the source probably being the warmer soils and/or the warmer ocean.

These slow feedbacks are not a model result. It is an empirical fact that they occur as global temperature changes. These amplifying feedbacks account for the large global paleoclimate changes in response to small perturbations of Earth's orbit. These slow feedbacks are not included in most models used in United Nations' studies, because they are not sufficiently well understood, and the speed at which they come into play is uncertain.[15] However, paleoclimate evidence indicates that these slow feedbacks amplify the eventual climate response by 50-100%. Thus the eventual response to 1000 GtC emissions may be 3-4°C rather than 2°C.

Target Implications. The 500 GtC fossil fuel emissions target is designed to avoid or at least minimize amplification of global warming by slow feedbacks. This result is accomplished by keeping global temperature within or close to the range of the Holocene, the current interglacial period. Slow feedbacks that occurred with the climate change from the last ice age to the Holocene, such as the three feedbacks discussed above, have already been activated, so little additional amplification would be expected if climate is kept at about Holocene level. Warming of 0.8°C in the past century, following a long-term cooling that preceded the industrial era, has brought global temperature back to approximately the Holocene maximum. Additional warming will occur in coming decades, because of Earth's present energy imbalance, but the 500 GtC emissions scenario would allow CO_2 to decline to about 350 ppm by century's end, with global temperature falling back to about its present value. The 350 ppm target may need to be adjusted as evidence accumulates, including data on non-CO_2 forcings. However, we know enough already for the conclusion: fossil fuel CO_2 emissions must be phased out as rapidly as possible.

The dramatic difference between 500 GtC and 1000 GtC targets becomes clear from just a few examples of expected climate impacts for the 2°C near-term warming from 1000 GtC and its eventual warming of 3-4°C. The last time Earth was 2°C warmer was during the Eemian period about 120,000 years ago. That warmth produced sea level at least 6 m (20 feet) higher than today, perhaps 8-9 meters higher. The last time Earth was 3-4°C warmer than today, in the Pliocene a few million years ago, sea level was 15-25 m higher, i.e., up to 80 feet higher, and the Arctic was 6-8°C warmer with heavily vegetated coastal regions around the Arctic Ocean.

Urgency of emission reductions. People concerned about climate change need to be aware of the urgency of achieving rapid emission reductions. Present economic incentives encourage people to go after every fossil fuel they can find, and they are being successful. If incentives are not changed soon, 1000 GtC emissions will become unavoidable. In that case, the consequences, even though they will take time to play out, will likely be unstoppable, a conclusion based on the fact that 1000 GtC emissions would cause ocean warming that would remain for centuries. Sea level rise would likely become unavoidable, because the main mechanism that causes ice sheets to disintegrate is the warm ocean, which melts protruding ice shelves that buttress the ice sheets.

What makes me think that people concerned about climate change may not appreciate the urgency of actions to avert locking in irreversible consequences? I give two examples:

[15] The United Nations studies focus on the next 87 years; it is uncertain how far slow feedbacks advance in 87 years.

A reliable source told me that Bill Gates has said "Jim Hansen is exaggerating." Gates is one of the world's wealthiest people, he is among the most effective philanthropists, and he is helping address some of the world's most difficult problems (such as disease and poverty). His opinion matters. Yet, if our assessment of the dangerous level of emissions is correct, emissions close to the 1000 GtC target will cause climate change at low latitudes with an impact there on disease and poverty that more than obviates all philanthropy in developing countries, underscoring the urgency of emissions reductions. Let's face it -- the most powerful individuals in the world are people such as Bill Gates. We need them to understand the urgency of effective policy actions -- they are essential to provide counterweight to the nearly omnipotent fossil fuel industry.

Environmental organizations are a second example. Some of the best organizations now use the 2°C global warming target. Perhaps they are motivated by a desire for widespread support, and it is easier to get international political agreement on a global warming limit of 2°C or ~1000 GtC emissions. Targets of 350 ppm CO_2 or ~500 GtC emissions may be perceived as implausible. If these organizations accept a target that is inadequate, it becomes more difficult to get policymakers to take the right actions, even when those actions make good economic sense.

The target must be based on what the science indicates, not what seems realistic. After all, how can we be sure what is realistic? What if China and India decided to replace their coal-fired units with modern safe nuclear power and we helped with the technology? What if the U.S. and China or Europe and China) also had a bi-lateral agreement for internal continually-rising carbon fees and imposed border duties on products from nations without an equivalent fee? If the business community and public realize that the fee will keep rising, it may be shocking how fast technological tipping points are reached, moving us toward a clean-energy, bustling economy and a better world.

Consequences

Our "Scientific Prescription" paper discusses consequences of global warming in detail. Here I mention three effects. I emphasize sea level rise and extermination of species, because they are irreversible. But I start with extreme events, because they concern people now.

Extreme events. Global warming increases the frequency, severity, duration, and spatial extent of extreme climatic events. This is easiest to demonstrate with summer temperature, because "weather noise" (natural variability) is least in the summer.[16]

Temperature data provide a nice opportunity to introduce simple concepts about statistics, which you should understand no matter what your interests are. I mean even if you decide that science is not your cup of tea, you should know something about statistics. However, the present letter is already too long, so I will write this as if we have already gone over that subject.[17]

[16] In winter there is a strong temperature difference between cold high latitudes and warm low latitudes, so winter temperature fluctuates a lot when the direction of the wind changes, i.e., it fluctuates as the weather pattern changes.
[17] The standard deviation is a measure of typical variability around the average. About two-thirds of the cases fall within 1 standard deviation of the average and about 95 percent fall within 2 standard deviations.

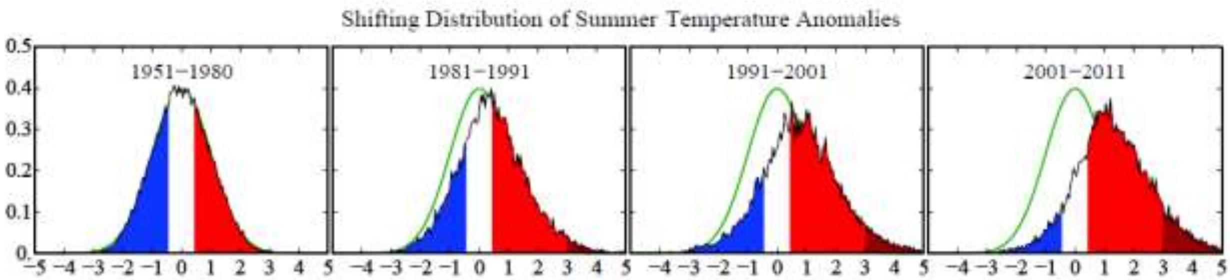

Fig. 8. Changing distribution of summer (June-July-August) temperature anomalies (relative to 1951-1980) for Northern Hemisphere in units of local standard deviation (horizontal axis).

The distribution of summer temperature anomalies 50 years ago is shown by the "bell curve" on the left end of Fig. 8. An anomaly is the difference between the actual summer-mean temperature in a given year and the long-term average. Some summers are unusually warm (the red side of the distribution) in the context of the 30-year period used to define long-term average conditions, and some summers are unusually cool (blue side of distribution).

The observational data show that this bell curve has been shifting to the right, decade-by-decade, over the past three decades (Fig. 8, 2nd-4th panels). This shift is global warming. The most important effect of this shift is the emergence of extreme hot outliers, defined as anomalies exceeding 3 standard deviations. This is the dark red or brown area on the hot tail of the bell curve. Such extremes occurred less than 1% of the time (and usually covered less than 1% of the land area) 50 years ago. But now these extreme hot anomalies cover about 10% of the land.

Such extreme hot anomalies covered a large area in Eastern Europe including Moscow in 2010, Texas-Oklahoma-Northern Mexico in 2011, and part of the Central Rockies and Great Plains in the United States in 2012. The areas hit in a given summer depend on the weather patterns that year, areas with prolonged high pressure tending to become extremely hot and dry, thus subject to strong drought and fires that burn hotter and are more damaging than in earlier decades.

Global warming has an equally important effect on an opposite climate extreme. A warmer atmosphere holds more water vapor, so at the times and places where precipitation occurs it tends to come in more extreme events, with heavier rainfall and more extreme floods. Floods that we had been accustomed to as unlikely "100-year floods" now occur more frequently.

The energy that is stored in water vapor when it evaporates, called latent heat, is the fuel that drives numerous storm types including thunderstorms, tornadoes and tropical storms. As a result of global warming these storms all have the potential to be stronger. We need consistent data over a long period to develop an accurate picture of how storms are changing, analogous to that which we have shown for seasonal mean temperature. However, there is already sufficient rainfall data to confirm the basic effect of warming on rainfall, as discussed in our paper.

The change in extremes since the mid-20th century is the response to the 0.6°C warming that has occurred since then. A target of 2°C for global warming would be 1.8°C warming after the mid-20th century, three times as great as that which has occurred so far since 1950. While we cannot predict the consequences of such warming exactly, clearly the temperature distribution in Fig. 8 would shift much further to the right, causing much more frequent and more severe climate extremes that would be even more damaging to society and ecosystems.

Sea level. Our best gauge of eventual sea level in response to long-lived global warming is provided by Earth's history, during which sea level consistently rose and fell in response to global temperature change. Typical rates of sea level change in Earth's history have been of the order of a meter per century, although rates as fast as 4-5 meters per century have occurred. There is no known increase of greenhouse gases or global warming in Earth's history as rapid as the present human-made change, so the paleoclimate responses do not necessarily indicate a limit for how rapidly sea level can change.

Paleoclimate data provides a good indication of the likely eventual sea level change for a given global warming, but it is less capable of predicting the rate at which sea level will change. The last time Earth was 2°C warmer than the pre-industrial level was during the Eemian interglacial period, about 120,000 years ago. Sea level reached at least 4-6 meters higher than today, and may have reached 8-9 meters near the end of that period. During the earlier Pliocene period, when Earth was about 3°C warmer than the pre-industrial level, sea level attained heights as much as 15-25 meters above today's level.

Climate change assessments by the United Nations focus on sea level rise by a specific year, 2100, i.e., 87 years in the future. It is expected that the next report, due later this year, will suggest that sea level rise by 2100 will fall in the range 0.5 to 2 meters, which is about double the estimate of the prior report. My opinion, as I have discussed in several papers, is that sea level rise in a century (if fossil fuel emissions continue to increase) could be much larger than that.

An ice sheet, such as those on Greenland, West Antarctica, and East Antarctica[18], will not melt at a nice smooth rate as if it were an ice cube sitting on a table in a warm room. Instead, an ice sheet's demise in a rapidly warming world is likely to be very "non-linear". It will release water and icebergs to the ocean at a generally increasing rate as the ice sheet "softens up" -- then a burst of ice and water is released to the ocean, with sea level rising as much as several meters in a century or less. There is much evidence of such "melt-water pulses" in paleoclimate data.

This implies that emphasis on predicting sea level at a specific moment in the future, 87 years from now, is misguided and misleading. It aids and abets the criminal insanity of setting a fossil fuel emissions target at 1000 GtC. That target guarantees global warming of 2°C and probably 3-4°C with the effect of slow feedbacks included. That target assures eventual sea level rise of many meters, possibly tens of meters. The uncertainty is only which generation of humans will bear the fastest rate of sea level rise. If we set the fossil fuel emissions target at 1000 GtC, we are wittingly sentencing future generations to sea level rise of many meters, because once the ocean has warmed, the warmth will be retained for many centuries.

Fossil fuel emissions of 1000 GtC mean that all of today's coastal cities, many with histories covering centuries, likely would be lost eventually. In the United States alone that means 1400 cities and towns,[19] globally tens of thousands. Let's leave aside the enormous economic implications. On ethical and moral grounds alone it is impossible to rationalize such a target.

[18] Antarctica is divided in two by a mountain range that stretches more than 2000 miles (about 3500 km).
[19] "Sea-level rise threatens 1,400 U.S. cities", Wendy Koch, USA Today, 29 July 2013.

Species extermination. Humans are putting pressures on other species in various ways, as we essentially take over the planet for our own uses. Climate change is an overarching additional stress, which could become the main cause of species extermination if global warming continues.

Species have been faced with large climate changes before. During Earth's history there have been several mass extinctions, when a large fraction of species disappeared forever. Evidence indicates that at least a few of these mass extinctions were caused by climate change. Some species adapted to the changing climate, and new species evolved over millions of years. However, such time scales are beyond common comprehension. If we exterminate many species, we will leave a more desolate planet "forever", as many generations as we can imagine.

Global warmings of 2°C or more have occurred during glacial-to-interglacial transitions without major species extinctions. However, the human-influenced situation differs in two fundamental ways that make it dangerous for life on our planet. First, the rate of global warming is much faster than has ever occurred naturally. Second, it is more difficult for nature to adapt to climate stresses now, because of other stresses and constraints that humans are causing for all species.

The best way to make the situation clear may be with a few examples. In a letter last year (Butterfly Report + Jeremiah, the Frog) I described the amazing Monarch butterfly, which migrates annually from Canada to a mountainous place in central Mexico, where it hibernates on a small patch of a specific fir tree. The trees are on a volcanic mountain, where a cloud belt forms around the mountain peak in the summer wet season. Somehow the Monarch is able to navigate its way back to this patch of trees, often to the specific tree that its great grandparent, or great great grandparent, had left in the spring when it headed north.

The Monarch's annual round trip is accomplished over three or four generations, as the female lays eggs on the leaves of milkweed plants, which provide the only food that the Monarch larvae (caterpillar) can eat, before they are miraculously transformed through the chrysalis stage into the beautiful orange and black butterfly. The DNA in this remarkable insect must contain all the information and navigational system to allow it to find its way to the patch of fir trees where its great grandparent left early that year.

The principal threat to the Monarch in recent years has been from herbicides that are used by farmers to kill weeds. As the number of milkweeds decreased, the Monarch population has declined. A few decades ago, Anniek and I were able to sometimes see 10 or 12 Monarchs at once on our property, but in recent years at most we have only seen one or two at a time.

So, as you know, that is why we began planting milkweeds a few years ago, to try to replace some of those lost to herbicides. In (Butterfly Report + Jeremiah, the Frog) last year I reported that Monarchs making it to the Mexican forest for the 2011-2012 winter were 30% fewer than the year before, presumably because of the severe drought of 2011 in Texas and Oklahoma.

Here I will tell you about a response to that "Butterfly Report", which I received from a Mexican scientist (Cuauhtemoc Saenz-Romero), and I can report on how many Monarchs made it to Mexico to hibernate for the 2012-2013 winter. The photo above shows Dr. Saenz-Romero's two-year-old son looking up at millions of Monarchs hibernating on these fir trees. Saenz-Romero and his colleagues report that these fir trees are under stress, as illustrated in Fig. 10, because of

Fig. 9. Monarchs in Abies religiosa (oxamel fir) in Mexico observed. Monarchs of Eastern North America overwinter on these trees at altitudes between 2.9-3.4 km at latitudes between 19°N and 20°N in the Trans-Mexican Volcanic Belt (Saenz-Romero et al., Forest Ecol. & Manag., 275, 2012).

persistent drought in this region during recent years. This tree damage, as well as illegal logging in this Butterfly Reserve, have contributed to the Monarch decline in recent years. This persistent drought seems to be a consequence of shifting climate zones and intensification of regional climate extremes associated with global warming.

Sanenz-Romero and colleagues conclude that these trees will not survive late in this century in their present location if CO_2 emissions and global warming continue on their present trajectory. They discuss the possibility of "assisted migration" for the Monarchs, which would involve planting the fir species at higher altitudes where they may be able to survive in the presence of global warming. However, they conclude that, if business-as-usual fossil fuel emissions continue, they must find higher mountains for fir tree survival. The prospects of success, for the Monarchs, of such "assisted migration" or "assisted colonization" seem somewhat dubious.

Now I can report on the number of Monarchs arriving in Mexico for the 2012-13 overwinter season: it was 59% less than the prior year. The number of Monarchs today is now only 7% of what it was 20 years ago, when accurate census taking began. The reduction in the past year was presumably due in part to the extreme drought of 2012, which was the most widespread in many years, as well as the climate and logging effects on the fir tree preserve.

This spring Connor, Jake and I planted more milkweeds by the butterfly bush next to the patio. The butterfly bush is now over six feet tall, with lots of purple flowers, so it should attract any Monarchs that happen by on their 5000-mile trip to Mexico, coming down to refuel or even lay some eggs. I check the bush and milkweeds every day that I am home. It's already August, but so far not a single Monarch, no evidence of eggs, no leaves munched by hungry caterpillars. Same story for the milkweeds between our front door and the lilac bush, the milkweeds that two years ago had a couple dozen caterpillars and we found chrysalises behind the shutter, on top of the window, and under the step: now not a single Monarch, no evidence of eggs, no leaves munched by hungry caterpillars.

Fig. 10. Drought-stressed fir trees in Butterfly Reserve. *Photo: C. Saenz-Romero*

Remember the first milkweeds you and Connor helped me transplant from Frogtown Road to the horse fence near our driveway entrance? They have multiplied to a lot of milkweeds now, some taller than the fence. But the same story for them: so far not a single Monarch, no evidence of eggs, no leaves munched by hungry caterpillars. So now the milkweed exercise causes a very different feeling than it did when the milkweeds were helping produce new butterflies.

However, we should not be discouraged -- 7% is still a lot of Monarchs. The species should survive if climate change is limited. Monarchs are an iconic species, and there is research underway aimed at finding herbicides that do not kill milkweeds. If additional global warming is only several tenths of a degree Celsius, the fir trees should still exist on their present mountain, although it may be necessary to plant some at increasing altitude.

Iconic species have an advantage. When I was a boy delivering the Omaha World Herald, I would always check a little box at the bottom of the front page that would give the number of whooping cranes that had arrived at their wintering area in Texas. The number of surviving cranes had reached a minimum of about 20 in the early 1940s, dangerously close to extinction. Their number slowly increased over the next couple of decades, thanks to special attention and heavy penalties imposed for killing any of these birds. Their biggest problem is loss of habitat, as humans have taken over most of the land. This year, when continuing drought in Texas threatened the whooping cranes, a federal judge ordered Texas officials to allocate water supplies to their nesting area, according to an article in the Wall Street Journal. Today there are about three to four hundred whooping cranes, which is still a small number. Your chance of seeing a whooping crane is pretty slim, even if you are traveling in their part of the continent.

Survival of species. It's not good enough to keep species just on the good side of extinction. One of the most impressive things in nature is massive wildlife numbers, whether it is a buffalo herd, a flock of flamingoes (not the plastic ones), or the Monarchs arriving in Mexico.

Preserving species one-by-one is not possible. There is a vast interdependency among the species, which humans will never be able to figure out entirely and replicate. We must learn to share the planet with the other species, preserving all or at least most of them.

The great biologist Ed Wilson has a vision. He believes the 21st century can just be a bottleneck for species. The species that make it through the bottleneck, most of the species, will be able to flourish again in a future in which humans do a better job of sharing the planet with the rest of nature, by bringing their own number and habits into better harmony with the rest of creation.

Indeed, survival of species is part of a larger matter. Given the strong human tendency to take over large areas of land, species preservation probably requires stabilizing and even reducing human population, which in turn depends upon elimination of poverty. It has been found in developed nations that fertility rates tend to fall to approximately the replenishment level or below that, when poverty is largely eliminated. Population of some developed countries is still rising, but that is mainly a result of increasing life expectancy and immigration of people who are escaping poverty in their homeland.

Pathways out of poverty, in turn, require availability of plentiful, inexpensive energy. Thus, a pathway to a better world requires a large supply of clean affordable energy. If that pathway is to be a world shared with the other species, it requires energy sources that are carbon-free, so that CO_2 emissions can be slowed rapidly and climate can be stabilized.

Ed Wilson's vision forces us to immediately recognize these larger issues that have vexed humanity for millennia. Yet we should not be discouraged. On the contrary, we have within our reach, almost at our fingertips, the means to address the fundamental difficult problems of human population and poverty. Solution of these problems depends on energy. Energy is connected directly to climate. And climate determines the prospects for all life on our planet.

Preservation of life as we know it requires that we retain a climate not too different from that of the Holocene, the climate of the last 10,000 years. If we allow climate to shoot far outside the Holocene range, at a rate that is an order of magnitude faster than species have previously experienced, we must expect that a large fraction of the species will not survive.

Preservation of creation, our planet's life, should itself be sufficient reason to cause a change of energy policy. However, when combined with the devastating practical effects of sea level rise and the impacts of a continual increase in extreme climate events, it is abundantly clear that we must develop a strategic energy approach.

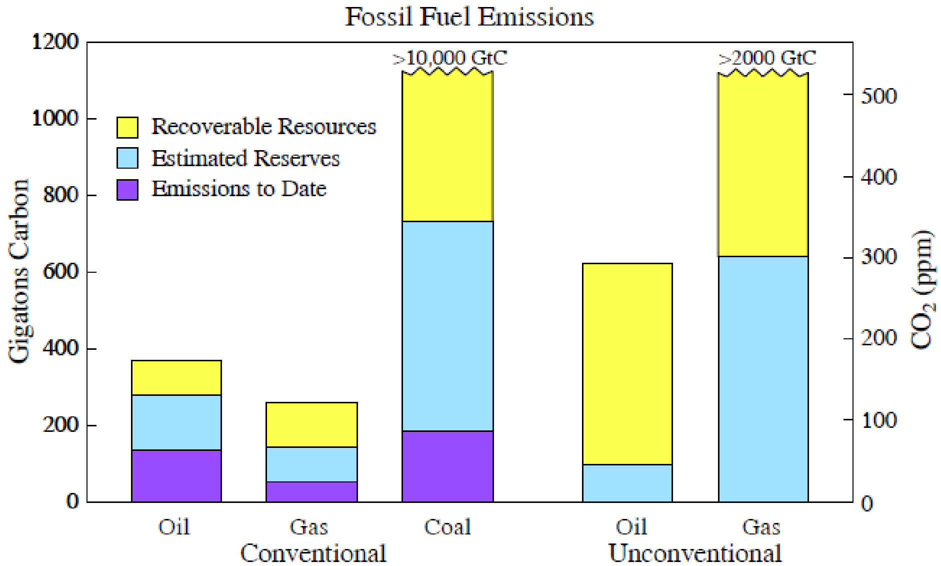

Fig. 2. CO_2 emissions from fossil fuels. Purple is amount emitted so far. Blue is fuel in known economically-extractable reserves. Yellow is further amount expected to become economically extractable as prices rise and technology improves. Fossil fuel emissions through 2012 are 370 GtC [1 ppm CO_2 ~ 2.12 GtC; ppm = parts per million; GtC = gigatons carbon; gigaton = 1 billion tons].

Fossil Fuel Strategy

An outline of the global strategy to limit climate change is apparent from a bar graph showing the carbon content of each fossil fuel (Fig. 2), which I repeat here for convenience and because it is so fundamental to our discussion. The bar graph, among other things, shows that, so far, we have burned only a small fraction of the total fossil fuel resource.

It is clear that if either the coal or unconventional fossil fuel (tar sands, tar shale, oil and gas from hydrofracking, etc.) were largely exploited, with the CO_2 emitted to the atmosphere, huge climate change would become unavoidable. Coal is very carbon-intensive (large amount of CO_2 per unit energy), and the unconventional fossil fuels are more carbon-intensive than their conventional counterparts because of the greater energy required to extract and process them. Coal and the unconventional fossil fuels share another characteristic: there is large regional and global air and water pollution caused by extraction, processing and burning of these fuels.

Thus it is obvious that the allowable budget for further carbon emissions should be allocated to conventional oil and gas. Oil and gas in remaining large pools, owned mainly by Middle Eastern countries and Russia, can be extracted at very low cost. There is no practical way to prevent this ready oil and gas from being extracted and burned. Indeed, this easily available oil and gas should be the transition fuel to the post fossil fuel era of clean energies.

Energy policies should be designed to spur rapid transition to clean energies. This transition would not only allow coal and unconventional fossil fuels to be left in the ground, it would also make it unnecessary to go to extreme environments to find the last drops of oil and gas.

Sophie, this outline of the fossil fuels we can afford to burn was already emerging more than 30 years ago. An early version of the fossil fuel bar graph was included in the first paper on CO_2

and climate that I submitted for publication with several colleagues in 1981.[20] I had to delete the bar graph to meet page length restrictions, but we kept the numbers and discussed implications. We noted that, as the climate signal was emerging from the "noise" in the remainder of the 20th century, governments would need to be developing carbon-free energies and energy efficiency.

The point is that the overall strategy governments needed to pursue was already emerging and it would become clearer and clearer as time passed. Yet actual government actions have instead allowed and encouraged pursuit of every fossil fuel that could be found, including development of an enormous potential for unconventional fossil fuels.

I will not dwell on reasons for this abject failure of governments. But perhaps it is worthwhile to briefly note three of the reasons. These became very obvious to me as I visited about a dozen nations, beginning in 2006, as partly chronicled in my book "Storms".

First, even in nations that are nominally democratic, some people are more equal than others. Stated simply, "money talks" in all capitals, and the fossil fuel industry has the most money.

Second, there is pervasive short-sightedness in our political system and society. We seem to have few statesmen in our governments, and even those so inclined are affected by the short election cycles. As for the public, although parents have always sacrificed for their children and grandchildren, the hectic pace of life today mitigates against thoughtful long-term consideration.

Third, many people who recognize the urgency of actions to alleviate climate change have been induced into accepting and promoting ineffectual policies, as I will clarify below. "Solutions" proffered are often based more on politics rather than objective assessment of what is needed.

Nevertheless, an effective fossil fuel strategy is still possible. "Experts" who say that we are already committed to 1000 GtC fossil fuel emissions or more are assuming that humanity is incapable of exercising any free will. We cannot acquiesce in the preposterous proposition that humanity necessarily will act as a bunch of lemmings marching unstoppably over a cliff.

Carbon Fee

Fossil fuel use has grown rapidly because fossil fuels appear to the public to be the cheapest energy. Cheap energy aids economic development and helps reduce poverty. However, as discussed in my earlier letter about "fee and dividend", fossil fuel cheapness is largely illusory. Let's summarize some of the main points here.

The fossil fuel industry receives direct subsidies from us, the taxpayers. In addition, human health costs of fossil fuel air and water pollution are paid by the public, not fossil fuel companies. The same is true for costs of climate disruption -- the government (i.e., taxpayers) provides some aid after climate disasters, but most costs are borne directly by the public -- meanwhile, the fossil fuel industry gets off scot-free. That's without even considering the huge costs of indirect subsidies, such as military protection of fossil fuel supply lines.

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[20] "Climate impact of increasing atmospheric carbon dioxide", seven authors, *Science*, **213**, 957-966, 1981. Paper was rejected twice by Science and once by Nature, each time because of excessive length. If was finally accepted after I squeezed it down to 10 journal pages.

Fee and dividend. The economy is most efficient, and thus people are best off, if energy prices are honest. We need a simple honest flat across-the-board fee on the carbon content of fossil fuels, gradually rising over time, the funds distributed 100 percent to the public, equal amounts to all legal residents, not one dime to enlarge the government. Such a "fee-and-dividend" system would cause fossil fuel CO_2 emissions to rapidly decline, most coal and unconventional fossil fuels would be left in the ground. Economic modeling for the U.S. shows that a \$10/tonCO_2 fee, rising \$10 each year, would reduce emissions 30 percent after a decade -- ten times more than the oil carried by the proposed Keystone XL pipeline, rendering that pipeline superfluous.

Business and innovation. Business leaders, such as Jim Rogers of Duke Power, say that what they need is knowledge of the carbon price and a general sense of how it will change. If we provide that, our captains-of-industry can be a huge part of the solution.

We have tremendous potential for innovation that will be spurred once there is a rising carbon price. New products, more jobs. As the carbon price rises, tipping points will be reached where low-carbon or no-carbon alternatives phase in rapidly, leaving fossil fuels in the ground.

Politics. Political reaction to fee-and-dividend provides insight. I gave a talk to international labor leaders. When I noted that fee-and-dividend lets the market place, rather than government bureaucrats, make decisions, one of them said "that's libertarian!" Well, so it is, with a small l.

After I gave a talk at one of Grover Norquist's meetings (on-the-record portion), one participant said "that's income redistribution!" Yes, fee-and-dividend is populist. Low-income people can gain by limiting their emissions. People with multiple houses, or who fly around the world a lot, will pay more in increased prices than they obtain in the dividend -- but they can afford that.

Fee-and-dividend is democratic - treating everybody equally - as well as libertarian and populist.

International implementation. The first international climate agreement, the Kyoto Protocol, was resoundingly ineffectual -- global fossil fuel emissions actually shot up faster. The Kyoto Protocol was a cap-and-trade-with-offsets scheme. Countries were begged to join and set emissions targets. If they failed to meet their target, they could withdraw from the Protocol.

Countries such as China will not accept a cap on their emissions. Why should they? Their per capita responsibility for excess CO_2 in the air today is small compared to the responsibility of the United States and Europe. If we wait until their responsibility matches ours, it will be too late.

Would China be willing to put a fee on carbon? Yes, for lots of reasons. They do not want to develop the fossil fuel addiction that plagues the U.S. They have heavy air and water pollution from fossil fuels, which is costly and has the public upset. They are among the most vulnerable nations to climate change, including sea level rise. China has a long history and seems to be able to take a long view. In the West our economists "discount" future climate impacts, assigning them a value near zero. There seems to be some basis to hope that China will be less prone to "discount" future impacts, heaping the consequences on the young.

Only a few nations would need to agree on a carbon fee -- say the United States and China or Europe and China. Those nations would place a border duty on products from countries that do not have an equivalent carbon fee. They could also rebate to their manufacturers the carbon fee covering the fraction of the manufacturers' production that is exported to nations without the carbon fee. This approach provides a tremendous incentive for other nations to adopt a similar domestic carbon fee, so they can collect it themselves rather than lose it as a border duty.

Criticisms of Fee-and-Dividend. A common criticism is that low income people will waste the dividend, e.g., buying powerball tickets. I come from a low-income family, my father a tenant farmer educated to 8th grade, with seven children. We would not have wasted the money. Nor would most low-income families. Sure, a minority of people will waste the money. You can't legislate against foolishness. But in such cases the money will soon be back in the economy.

Another criticism of fee-and-dividend that some people have made is that it would be better for the government to take the collected fee and invest it in clean energies. Uh, they think the government can make the best choice for winning technologies? That should be an easy call.

Failure of government to invest wisely in advanced technologies is so blatant that even long-lead research and development, such as advanced-generation nuclear power, is now being financed privately. Quietly, despite continuing failure of government to make fossil fuels pay their costs, exciting advances are being made in many technologies. These technologies could spread like wildfire once a rising carbon fee is collected and distributed to the public, so that fossil fuels begin to pay their true costs and the public has funds at their disposal.

Still another criticism is that the fee collected should be used to pay down the national debt. The public is not stupid. If the money is thrown into government coffers, regardless of how its use is described, the public will know it is being used to support big government. The only way the public will allow a continually rising price on carbon is if the money goes to them, so that they can deal with increasing fossil fuel prices. The rallying cry should be "100 percent or fight!"

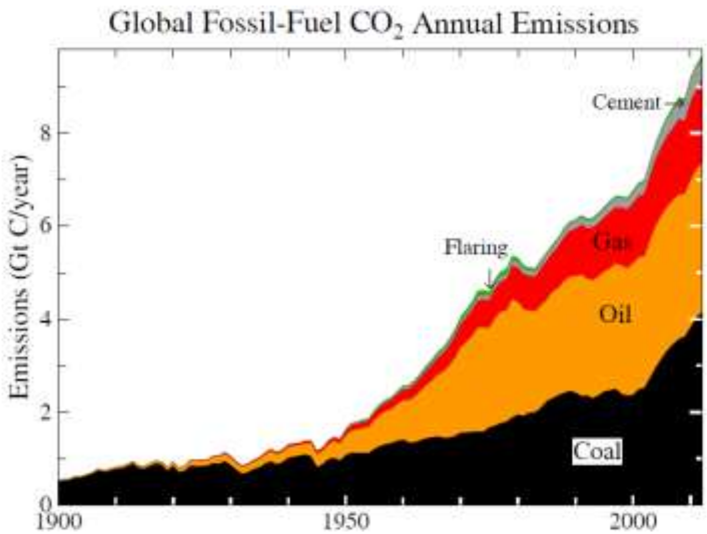

Fig. 11. CO_2 annual emissions from fossil fuel use and cement manufacture.

Alternative Energies

Fossil fuel CO_2 emissions, which grew at an average rate of 1.5%/year prior to the 1997 Kyoto Protocol accelerated to an average 3%/year growth rate thereafter. Acceleration of emissions was mainly due to a near doubling of coal emissions (Fig. 11). Growth of coal use occurred especially in China and India, while high coal use continued in the United States.

Fossil fuels provide more than 85% of the world's energy (Fig. 12). Coal provides about 30% of global energy (Fig. 12), but a much larger fraction of CO_2 emissions (Fig. 11), in part because coal produces more CO_2 per unit energy than oil or gas.

Nuclear power and hydropower presently are the largest energy alternatives to fossil fuels. The largest alternative energy in the U.S. is nuclear power at 8%. Globally, nuclear power (5%) is exceeded by hydropower (6%), mainly because the largest energy user, China, so far has < 1% of its energy from nuclear power.

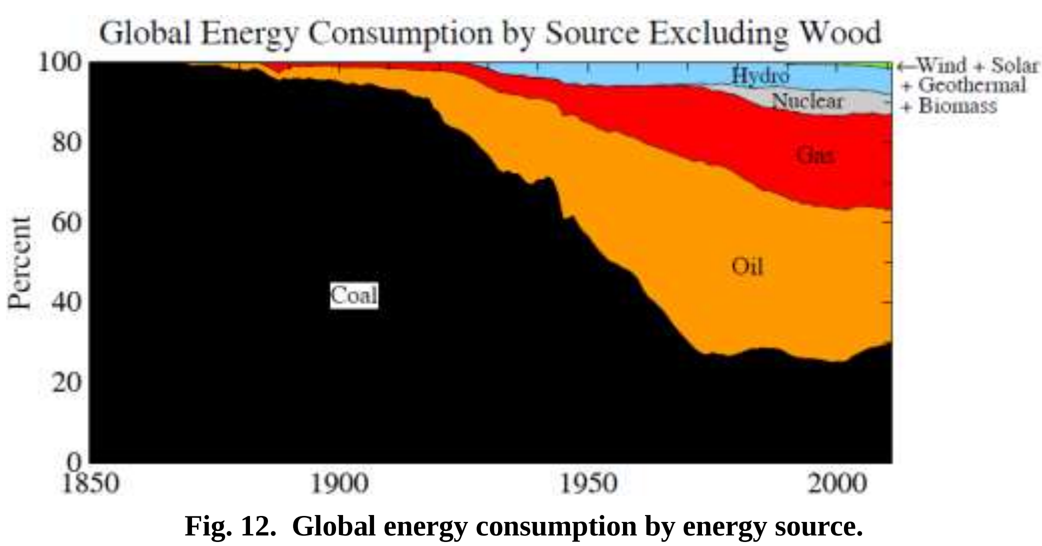

Fig. 12. Global energy consumption by energy source.

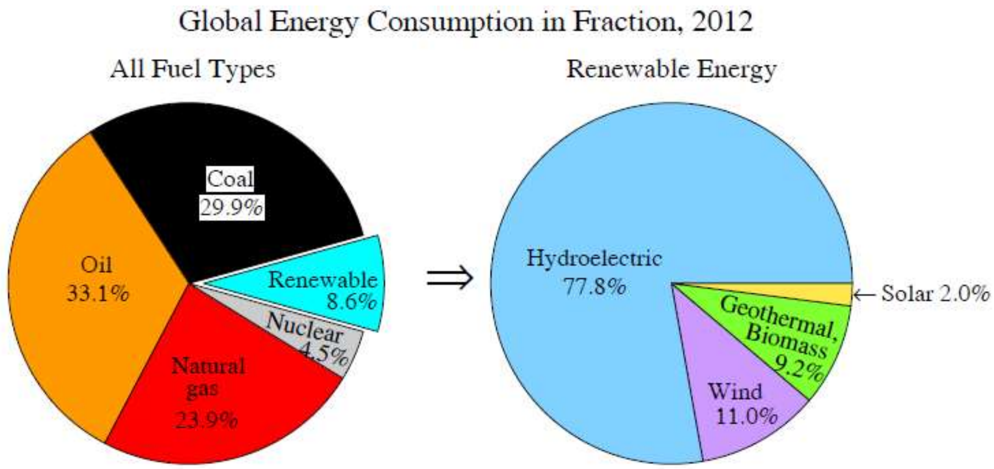

Fig. 13. Global energy consumption by energy source (Mtoe = million tons oil equivalent).

The magnitude of the task of replacing fossil fuel energy is enormous. The total global non-hydro renewable energy (wind, solar, geothermal, biofuels) developed over several decades (now 1.9% of global energy, Fig. 13) approximates the growth of global energy use in a single year.

Fossil fuels will dominate world energy as long as they seem to be the cheapest energy. Fossil fuels are cheap only because they do not pay their costs to society, including health effects of air and water pollution, environmental damage from mining, and growing climate change impacts.

Sorry to dwell on the carbon fee! You must be fed up with reading about it! It is o.k. to skip the following paragraph! However, the matter is so fundamental, I must summarize the situation.

A continually rising carbon fee provides the economically efficient way to phase down fossil fuel use and phase in energy alternatives and improved energy efficiency, as discussed earlier. A simple flat carbon fee, collected at domestic mines and ports of entry, can be made international via an agreement between a few major nations such as the U.S., China and the European Union. Other nations would join to avoid border duties on their products. Conventional oil and gas would provide transition energy, phasing down as clean energies and energy efficiency phase in.

Environmental Cooperation and Understanding

It's a huge task to replace fossil fuel energy with clean energy. People who know the urgency, environmentalists in particular, should cooperate and focus on that task. If instead they belittle alternative energies that they do not prefer, the fossil fuel industry will be the benefactor and young people will suffer the consequences of our stupidity.

There are pros and cons to every energy source. Some regions are well-endowed with potential for certain energies but not other energies. Local public preferences also must be considered.

For example, some people are happy with wind power and consider modern windmills to be attractive. Other people object to the effect of windmills on the landscape, as well as windmill noise and bird kill, and the possible need for new cross-country transmission lines to take the energy from where it is produced to where it is needed. As a result, preferences for energy sources are likely to vary from one country to another and from state to state.

That diversity is not a problem. On the contrary, it provides opportunities to test and compare alternatives. What is a problem is bickering among environmental advocates of specific energies and mutual recriminations. We must develop all non-carbon energies to phase out fossil fuels. If some energy sources prove superior to others that will be fine, they can assume dominance on the long run, but for now we should all be on the same side, working to halt carbon emissions.

That may sound like apple pie and motherhood, something everyone can support. Unfortunately, reality differs. I find, as I begin to mention implications of climate change for energy choices, a gross asymmetry between people who advocate "renewable" energies as the only alternative to fossil fuels and people who argue that nuclear power should be included in the energy mix to allow fossil fuel use to be phased down rapidly.

I am among the people who argue that nuclear power has an important role to play in providing baseload electric power. For example, nuclear power seems to provide the only realistic chance for rapid replacement of coal-fired electricity in China and India, the largest and fastest-growing source of atmospheric CO_2. Yet I also strongly support renewable energies. As you know, our barn roof is covered with solar panels that, even averaged over the year, generate twice as much electricity as we use. I helped get solar panels onto your roof that generate almost as much electricity as those on our barn (and, to my mock chagrin, they have a higher efficiency!).

In contrast, people advocating renewable energy are often vociferously anti-nuclear. The result is widespread public misunderstandings about nuclear power, with impacts on public policies.

Sophie, this topic is so important for the future of life on our planet that I will write a separate letter on the topic. The nuclear power story is not really difficult, but this letter is already very long, so I will just summarize the highlights.

Nuclear Power

United States President Dwight Eisenhower delivered a speech, "Atoms for Peace", in 1953 at the United Nations. Eisenhower proposed that nuclear technology, which previously had been classified and restricted to military applications, should be made available to civilians for peaceful purposes. Eisenhower spoke at a time of public fear. The nuclear Pandora Box had opened with the hectic race to build the first nuclear weapons, dropping of atomic bombs by the U.S. on Japan, and initiation of massive nuclear arms buildup in the West and the Soviet Union.

Others may question Eisenhower's motives, but I believe he meant what he said: "It is with the book of history, and not with isolated pages, that the United States will ever wish to be identified. My country wants to be constructive, not destructive. It wants agreements, not wars, among nations. It wants itself to live in freedom, and in the confidence that the people of every other nation enjoy equally the right of choosing their own way of life."

Eisenhower recognized that making nuclear technology available for peaceful civilian purposes carried a responsibility to help assure the technology would not be used for destructive purposes: "To the making of these fateful decisions, the United States pledges before you -- and therefore before the world -- its determination to help solve the fearful atomic dilemma -- to devote its entire heart and mind to find the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life."

Nuclear power provided a natural energy evolution beyond fossil fuels. Just as fossil fuels were more compact energy than wood, nuclear fuel is even much more compact. Uranium or other nuclear fuel the size of a golf ball contains all the energy used by a U.S. citizen in a lifetime.

Of course, people do not carry nuclear fuel in their vehicle or "burn" it in their home. Instead electricity is generated by nuclear power plants. Electricity is our fastest growing energy carrier and it is clean. Electricity can even be used to power many of our vehicles and provide heating. Nuclear power can also be used to make liquid fuels, needed for some transportation purposes including aircraft, but that technology will be undeveloped as long as fossil fuels are cheap.

The first commercial nuclear reactors were based on the design that had been developed by the military to power submarines, and later aircraft carriers. These were "light-water" reactors. You don't need to worry about technical details, but I will clarify a few things in my "nuclear" letter. In these light-water reactors normal water is used to slow the speed of nuclear particles in the reactor and to cool the reactor. Hyman Rickover of the U.S. Navy chose this design for nuclear powered submarines, which made good sense for that purpose. This design is sufficient to allow a small amount of uranium to power a submarine for years without refueling.

Leading nuclear physicists preferred that civilian nuclear power plants would soon also include "fast" reactors, which allow nuclear particles to move fast enough to "burn" more than 99% of the nuclear fuel. Slow light-water reactors burn only about 1% of the nuclear fuel, leaving a "nuclear waste" pile that remains radioactive for tens of thousands of years. Fortunately, the fast reactors can use the "waste" from the slow reactors as fuel. Fast reactors leave a smaller waste pile with a "half-life"[21] of decades, so its radioactivity is negligible after several hundred years.

Peaceful use of nuclear power thus began with the light-water reactors, because they were a tested technology ready to go. They were called "2nd generation" nuclear technology, with 1st generation referring to prior experimental reactors. Almost all of the nuclear power plants in use today are 2nd generation, i.e., technology that was developed about half a century ago.

Approximately 100 of these 2nd generation light-water nuclear power plants were built in the United States about 50 years ago. Proponents of nuclear power presumed that by this time we would also have fast reactors that could dispose of nuclear waste from the light-water reactors. So far it has not worked out that way. Instead of fast reactors, the primary alternative to 2nd generation nuclear power has been coal. Gas, with the help of the "fracking" boom, is beginning to replace coal-fired power plants and could also supplant nuclear power plants.

The history of how we went down this path is curious and relevant. Here are key 'highlights."

President Carter. On 18 April 1977 President Jimmy Carter delivered a televised Energy Policy speech to the American people, beginning: "Tonight I want to have an unpleasant talk with you

[21] The radioactivity decays "exponentially". After one half-life, say 10 years, the radioactive emissions are only half as large as they were initially. After another 10 years it is reduced by half again. It never becomes zero, but after several centuries the radiation is negligible, less than natural background radiation.

about a problem unprecedented in our history. With the exception of preventing war, this is the greatest challenge our country will face during our lifetimes. The energy crisis has not yet overwhelmed us, but it will if we do not act quickly."

Maybe not a bad beginning. It did not need to be so negative and unpleasant, but by the end of the talk, when he reveals his policies, there was abundant reason to feel very unpleasant.

President Carter defined a national energy plan based on 10 fundamental principles. The first eight principles emphasize the need for everybody to make sacrifices and use less energy. However, it is the final two principles that are enough to make a grown man cry, once the implications of those two principles become clear.

"The ninth principle is that we must conserve the fuels that are scarcest and make the most of those that are more plentiful. We can't continue to use oil and gas for 75 percent of our consumption when they make up seven percent of our domestic reserves. We need to shift to plentiful coal while taking care to protect the environment, and to apply stricter safety standards to nuclear energy."

"The tenth principle is that we must start now to develop the new, unconventional sources of energy we will rely on in the next century."

Actions initiated to implement the latter two principles had a lasting effect by increasing our dependence on fossil fuels, making it more difficult now to rapidly reduce carbon emissions. President Carter was and is a very good man, working tirelessly on humanitarian projects. Although it has subsequently become clear that his policy choices were harmful, it would be inappropriate to single him out for blame. There were later opportunities to alter our course, after the climate and energy issues had become clearer, yet our subsequent leaders failed to take advantage of those opportunities. President Carter should be given credit for speaking bluntly to the public and trying to set a course, albeit a terribly flawed one.

One flaw was his choice to move to greater use of coal and unconventional fossil fuels, which we now realize we cannot burn and still maintain a planet looking like the one we know. His policy helped to make coal our main source of electricity. Carter also initiated efforts to develop unconventional fossil fuels, including use of coal to make oil and gas. These efforts slowed when Carter's prediction that global oil production would begin to decline within 6-8 years proved to be wrong, but they were big steps down the unconventional oil and gas path.

Carter's second major impact on carbon emissions was via his policies affecting nuclear power, which he had elaborated in a separate announcement on 7 April 1977. Specifically, he said that the United States would defer indefinitely the "reprocessing" (see below) of nuclear waste. His explanation was that this action would reduce the danger of nuclear weapons proliferation, and by setting this example the United States would encourage other nations to follow its lead.

This policy was a blow to those nuclear scientists who had devoted their efforts to "beating the sword into plowshares." If nuclear "waste" was not reprocessed it could not be used as fuel in "fast" nuclear reactors. In that event the "waste" would indeed be waste, not fuel for reactors that could extract the other 99% of the energy it contained. Humanity would need to babysit this waste for tens of thousands of years before its radioactivity would decline to a harmless level.

Sophie, I am writing a separate letter on nuclear physics to make nuclear energy less mysterious. If the public had a good understanding of all fuels it would help them make an honest assessment of merits and demerits. For now, I just note that when nuclear scientists say they want to "close the fuel cycle" they are essentially saying that they want to burn the other 99% of the energy in the original nuclear fuel. To do that, they must "reprocess" the nuclear "waste."

So nuclear scientists were dismayed by President Carter's "no reprocessing" order of 7 April 1977. It prevented them from closing the fuel cycle, and they realized that civilian nuclear power makes much less sense if we only use 1% of the nuclear energy. First, it means the public is stuck with a baby-sitting job for tens of thousands of years -- that won't go over very well! Second, it means that we must continue mining uranium indefinitely, and easily available uranium might last only a few centuries, not much longer than fossil fuels.

In contrast, if the fuel cycle is closed, we already have enough fuel in nuclear "waste" and excess weapons material (which also can be burned in fast reactors) to satisfy the world's energy needs for almost 1000 years. And long before that point is reached, we will have perfected methods to extract uranium from sea water, providing enough nuclear fuel to last billions of years. In other words, nuclear fuel will be inexhaustible. That will put nuclear power it in the same category as solar and wind power -- all of them will last as long as a habitable Earth exists. Nuclear power has the advantage that it provides continuous base-load electric power.[22]

Eisenhower's thinking and Carter's thinking contrasted sharply. Eisenhower emphasized the potential of abundant energy to serve humankind and alleviate world poverty. Carter saw a danger in nuclear power and preferred a path in which the public make sacrifices and accepted the need to live with less energy. Of course, everyone agrees that first priority should be given to increasing energy efficiency, thus reducing energy demands and pressures on the environment. Yet there were fundamental differences in the proposed approaches, as we will see.

Eisenhower proposed an International Atomic Energy Agency (which indeed was established in 1957). Eisenhower had said: "The Atomic Energy Agency could be made responsible for the impounding, storage, and protection of the contributed fissionable and other materials. The ingenuity of our scientists will provide special safe conditions under which such a bank of fissionable material can be made essentially immune to surprise seizure. The important responsibility of this Atomic Energy Agency would be to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind. Experts would be mobilized to apply atomic energy to the needs of agriculture, medicine, and other peaceful activities. A special purpose would be to provide abundant electrical energy in the power-starved areas of the world. Thus, the contributing powers would be dedicating some of their strength to serve the needs rather than the fears of mankind."

[22] We should take advantage of all these energy sources. Solar and wind power are intermittent, yet they can be used effectively. Solar power, e.g., peaks in the afternoon, when power demand is usually largest.

Carter's policy was dominated by fear that nuclear material could be used to make a weapon. If his policy eliminated all nuclear threats from the planet, it may be worth losing the promise of nuclear energy. However, by blocking the reprocessing of nuclear waste, Carter was affecting only one of several possible sources of nuclear material -- and not the most likely sources that rogue nations or terrorists would employ. Furthermore, any success of Carter's policy depended on his assumption that other nations would follow the U.S. example; that hope was dashed as half a dozen other countries with nuclear capability have refused to forgo reprocessing and fast reactors. Nuclear experts who I have consulted say that Carter's hope of a simple policy that would eliminate or minimize nuclear dangers was not a plausible solution to begin with.

The upshot of Carter's policy was negligible effect on the world's nuclear "sword", but a heavy blow to the "plowshare." Nuclear research and development on improved technology, which could operate more safely, close the fuel cycle, and thus solve the nuclear waste problem, was slowed dramatically. In my letter on nuclear physics I will discuss nuclear technology and the "proliferation" issue more. The conclusion is that the most effective policy is for the United States to stay at the forefront of nuclear research and development. That provides the best ability to work with other nations to develop the safest nuclear technology and minimize the possibility that weapons material will be acquired by rogue nations or terrorists. It would also allow exploitation of the great potential of nuclear energy for peaceful purposes.

In the meantime, events occurred that had major repercussions for nuclear power.

Nuclear Accidents. On 28 March 1979 the worst accident in the history of U.S. nuclear power plants occurred in one of the two Three Mile Island nuclear reactors. An overheating and partial meltdown of the reactor core caused release of radioactive gases into the atmosphere. The amount of radiation released was small, but there was much confusion and anxiety. The Governor of Pennsylvania recommended that pregnant women and pre-school children living within 20 miles of the plant evacuate the area. About 140,000 people of the 660,000 people living within 20 miles did evacuate, most of them returning within several days.

The Three Mile Island accident caused a great deal of concern, in the United States and the rest of the world, about the safety of nuclear power. Public concern was heightened by the coincidental release, a few weeks earlier, of the China Syndrome, a movie about a nuclear reactor accident starring Jack Lemmon and Jane Fonda. Public anti-nuclear demonstrations followed, highlighted by a concert in Central Park, New York City, featuring Jane Fonda and Carly Simon. If you check the youtube video in the prior sentence, you can see the size of the crowd, which was more than 100,000 people.

It is relevant to compare the size of anti-nuclear rallies and anti-coal rallies. How many people were at the rally in Washington that you and Connor marched in? You two, plus your mother and me, made up a significant fraction of the total. Of course, that's not a valid comparison, because the march we went to was organized by young people without resources or a film star attraction. However, even organized anti-coal rallies, including one featuring the arrest of film star Daryl Hannah, drew only hundreds of people. Anti-nuclear rallies are much larger.

Another relevant comparison is the number of people killed by nuclear power and coal. It has been estimated that the radiation exposure of Pennsylvania citizens caused by the Three Mile

Island accident could lead to one or two cancer deaths, among the 40,000 cancer deaths that will occur among that population due to other causes. The radiation from Three Mile Island was approximately equal to the extra radiation that people expose themselves to by making two cross-country aircraft flights. We are exposed to radiation naturally, and radiation levels are higher at the altitudes where jetliners fly.

However, the estimate that Three Mile Island might cause one or two deaths is based on a so-called "linear-no-threshold" (LNT) assumption. The LNT assumption simply means that known detrimental effects that occur with extreme doses of radiation are assumed to also occur with small doses of radiation, with the impact reduced in proportion to the radiation amount. Medical research is inadequate for definitive conclusions (that would require empirical data covering decades, with comparable populations exposed to different radiation levels), but some evidence suggests that low levels of radiation might actually be beneficial, i.e., low levels of radiation may reduce deaths rather than increase deaths. This is plausible, because it is well known that radiation can kill cancer cells. Also, life developed on a planet bathed in low levels of radiation; successful life forms tend to be those that take advantage of their environment.

Although it may be more amusing than meaningful, I know several physicists who vacation once a year in a region with unusually high natural radiation. They say they want to get their annual dose of preventive radiation to assure long life. I get the sense that they are extremely frustrated with their inability to communicate at a level competing with the likes of Jane Fonda and environmental groups, such as Greenpeace and Friends of the Earth, which have vociferously taken up the anti-nuke cause.

There have been nuclear accidents much more serious than Three Mile Island, specifically Chernobyl in 1986 and Fukushima in 2011. Chernobyl caused about 43 deaths so far, and it is predicted that an eventual death toll from cancer could reach 4,000 to 25,000; however, this type of extrapolation is uncertain, and the death toll could be much lower. Fukushima has not caused any deaths from radiation so far. The World Health Organization reported this year that most residents around Fukushima were exposed to so little radiation that effects would not be detectable, but the lifetime cancer risk for those infants (who are most susceptible) in the most affected areas would increase about 1%. "Anti-nuke" people sometimes assert larger number of casualties from these accidents, but scientific studies do not support them.

Let's compare deaths caused by nuclear power with deaths caused by other energy sources. Important insight is provided by an inadvertent experiment in China during the 1950-1980 period of central planning. Free coal for winter heating was provided to North China but not to the rest of the country. The effect of resulting air pollution has been determined using the most comprehensive data file ever compiled on mortality and air pollution in any developing country. It is found that the air pollution from coal burning caused more than one million deaths per year among the 500 million residents of North China. On average the life expectancy of people in North China was reduced 5.5 years.

Of course, air pollution in China exceeded that in most of the world. However, even conservative estimates of deaths in the United States from fossil fuel air pollution exceed 40,000 per year. A question we need to consider: why do these deaths caused by fossil fuels not provoke the anguish associated with the much smaller number of deaths caused by nuclear accidents?

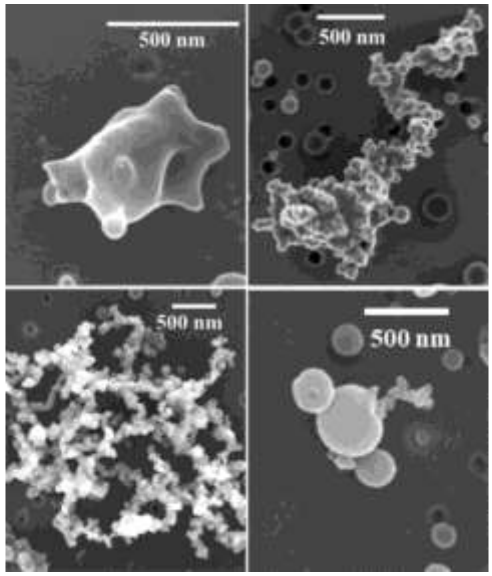

Fig. 14. Images of soot particles (500 nm is 0.5 microns, half of a thousandth of 1 millimeter).

Perhaps part of the "success" of anti-nukes in creating public fear[23] of nuclear power is the public's unfamiliarity with nuclear matter, compared with coal, for example, which they can hold in their hands. It may help if we can create some familiarity with the offending particles.

Fossil fuel air pollution contains an enormous number of tiny black soot particles, formed of complex organic (from previously living organisms) and inorganic carbon compounds. The most damaging particles are too small to be seen with the naked eye, about one micron[24] in diameter or smaller. Magnified images show that the soot includes some real ugly particles.

However, the scariest thing about these particles is this: when you breath air containing black soot and organic carbon pollution, these ugly particles not only become lodged in your lungs -- many of them enter your bloodstream! Medical research in the past two decades shows that fossil fuel air pollutants cause not only pulmonary health problems (asthma, lung cancer, etc.), but also cardiac problems, increasing the risk of heart attacks. It becomes easier to see how the air pollution from coal burning could kill one million people per year in China.

Deaths are only one measure of harm. The number of people whose health and quality of life is damaged by this pollution greatly exceeds those who lose their lives. And I have not even discussed the water pollution from fossil fuels, which includes mercury deposited in lakes and the ocean, which enters our food supply and, among other things, affects the IQ of children.

Yet somehow these horrific pollutants from fossil fuels cannot generate a rally of 100,000 in Central Park. Not even close. It is worth watching the 3-minute video of the concert at which Jane Fonda and Carly Simon are able to get 100,000 people to swing and sway with them. Opposing nuclear power seems to be much sexier than opposing coal. The ironic thing about the

[23] An anti-nuke scientist, who had to admit that radiation released by the Fukushima accident had not killed anyone, decried the psychological effects that the fear of ionizing radiation would have on the Japanese people. The irony, given the fact that he had spend much of his life whipping up that fear, did not seem to occur to him.

[24] A micron is a millionth of a meter or a thousandth of a millimeter (mm). An inch is 25.4 mm or 2.54 centimeters.

Central Park rally is that, while singing that nuclear power costs lives, they praise the comforting glow of a wood fire.[25] Wood fires produce indoor air pollution, and over years have killed millions of people. Sometimes knowledge is important. This seems to be one of those times.

I do not make light of the damage caused by the Chernobyl and Fukushima accidents. Chernobyl caused widespread health effects and fatalities. Both accidents forced long-term evacuation of areas around the reactors. Residents there suffer grievously from the foolishness of early nuclear designs and decisions. (The Chernobyl reactor was not in a building that could contain most of the radiation. Fukushima was built at a low height in a region where tsunamis are likely, with backup power in the basement.) Fukushima continues to leak radiation to the sea.

What I am saying is that the fears whipped up by anti-nukes are exaggerated. I have received scores of e-mails from people distraught by Fukushima. One message, after media reports that small amounts of radiation would reach the United States, was titled: "We are all going to die!" More heart-rending are the many messages that I receive (almost all from women) begging me to read warnings of certain anti-nukes (see hama-hama-hama boys below) and asking me to condemn future use of nuclear power for the sake of their children.

Of course, we must prevent future accidents like Chernobyl or Fukushima. As for contaminated water leaking from Fukushima, one should not drink it or swim in it any more than one should drink or swim in the effluents emerging from thousands of industrial plants around the world. Radiation from Fukushima, when mixed into the world's ocean, is negligible, but precautions should be taken about possible contamination of local sea life until local levels are negligible. That does not mean that I am recommending an approach the world employed for centuries: "the solution to pollution is dilution." What I emphasize is that the nuclear industry, already the safest of all major industries, has the potential to be even much safer.

When early commercial aircraft experienced accidents, some killing hundreds of people in a single accident, did we demand that all aircraft should be destroyed and we would not allow any new aircraft to be built? Of course not. We learned from the accidents and we built safer planes and we developed improved procedures for operating them.

The same is true for nuclear technology. A Chernobyl-like power plant would never be built again -- in fact one was never built in the West. Most Fukushima problems could have been avoided even with its 50-year-old technology. However, current technology reduces the chance of serious accidents via features such as automatic shutdown in case of an earthquake or other anomalies with convective cooling of the reactor that does not require exterior power.

My colleague Pushker Kharecha and I recently published a paper showing that nuclear power in the past saved at least 1.8 million lives and prevented tens of billions of tons of CO_2 emissions by displacing fossil fuel power plants. Nuclear power in the future has the potential to save many more lives and prevent much more CO_2 emissions.

[25] There is a huge difference between the occasional convivial winter fireplace and a situation where families are using wood, cobs, or coal as the fuel for heating their home. I know; I have experienced both.

President Clinton. Nuclear capacity in the United States grew rapidly in the 1960 and 1970s, but growth had slowed before the 1979 Three Mile Island accident. The biggest problem for nuclear power was the cost of new power plants. Coal was plentiful, cheap and not required to pay for its cost to society, such as environmental damage and human health effects of pollution. Such costs are all borne, thus "subsidized," by the public. Anti-nuclear groups learned they could increase nuclear costs via legal challenges that delayed construction schedules. After Three Mile Island orders for nuclear power plants dried up and most existing orders were cancelled.

On the other hand, the issue of human-made climate change became well known in the 1980s, with its implication that fossil fuel emissions must be phased out. France, for the sake of energy independence from oil states, increased its nuclear power generation by a factor of 15 in one decade, 1977-1987. This increased the nuclear portion of its electricity from 8% to 77%, thus illustrating how fast it would be possible to phase out fossil fuel use for electricity.

Still, if nuclear power is to play a major role in averting large climate change, it would be essential to close the nuclear fuel cycle. That is necessary not only to utilize all of the energy in the nuclear fuel, rather than 1%, thus making nuclear fuel inexhaustible for billions of years -- it is also necessary to solve the nuclear waste problem.

Fortunately, a moderate level of nuclear research and development had continued in the U.S. Department of Energy, mainly at Argonne National Laboratory. By 1992 Argonne had tested the essential components and was ready to build a reprocessing plant that could be combined as an integral part of a "fast" nuclear reactor able to utilize over 99% of the nuclear fuel. With this reprocessing method, called "pyroprocessing", the fast reactor would be less vulnerable than prior approaches to the possibility of theft of nuclear material by rogue nations or terrorists. The "fast" reactor in which Argonne planned to incorporate this reprocessing would be provided by the private sector, by a consortium headed by General Electric but with several partners including Westinghouse, Bechtel, Babcock & Wilcox, Raytheon, and others. It would be a significant step toward safer use of nuclear power for peaceful purposes, as envisaged by Eisenhower and others who aimed to "beat the sword into plowshares".

Thus, it came as a rude dispiriting shock when President William Clinton, in his first State-of-the-Union message in January 1993 declared: "We are eliminating programs that are no longer needed, such as nuclear power research and development."

This was a momentous sweeping decision about a complex matter. It had enormous implications for our potential to deal with climate change, a matter that Clinton and his running mate, Al Gore, were well acquainted with.

What was the basis for Clinton's quick decision? Where was he getting his technical advice? Did he receive good science and engineering advice?

Over the past decade I have learned a lot about these questions from people who were involved in the science, in the engineering, and in the politics. I will discuss these matters in my letter on nuclear physics. However, there is one implication of Clinton's momentous action that is so important that I will summarize it -- right after I tell you about the biggest con job in the almost 5-billion-year history of our planet.

The Biggest Con Job in the History of Planet Earth

A Simple Physics Story. Sophie, about the time of your 6th birthday, in 2004, I was preparing for a public talk. That's when I asked your mother to take a photo of you and Connor, who was just a few months old, holding tiny Christmas tree bulbs. I hoped the photo could help me make clear the simple physics story that is the climate story. I hated giving talks, was not good at it, and had avoided any high profile talk for 15 years. The talk was supposed to have been given in Washington, DC, but the organizers withdrew their invitation. However, Prof. Van Allen arranged for the talk to be given in Iowa City. I read the entire talk.

One of the charts that I showed, and read, was a quotation of the famous physicist, Richard Feynman: "The only way to have real success in science … is to describe the evidence very carefully without regard to the way you feel it should be. If you have a theory, you must try to explain what's good about it and what's bad about it equally. In science you learn a sort of standard integrity and honesty."

Feynman's quote sums up nicely what I discussed in my earlier letter "How Science Works." Feynman's advice seems simple, but actually it is very hard, is seems you have to fight human nature. Science, if you learn it well, teaches you how to be objective and not fool yourself.

North Carolina Gentlemen. In the few years after my Iowa talk I gave occasional talks. One talk was in North Carolina at the invitation of Jim Warren, the Executive Director of NC WARN (North Carolina Waste Awareness & Reduction Network). An energy efficiency expert gave a second talk that evening. Our talks were followed by Q&A (question and answer) with the audience. Before we went out for our talks, Jim Warren told me that there were likely to be questions about nuclear power. He noted that he was strongly opposed to nuclear power, but that I should feel free to give my own answer (without regard to the fact that he had invited me and was paying my expenses). He was sincere, even though he had devoted much of his life to fighting nuclear power. He was in every way a perfect gentleman.

Indeed, I was asked about nuclear power. I don't remember my exact answer. I know it was wishy washy, pointing out the merits of nuclear power for helping us reduce CO_2 emissions, but also pointing out the criticisms of nuclear power that cause people to hesitate. That sort of non-answer seemed to be a common response from climate scientists. The audience at climate talks is usually made up largely of environmentalists, who tend to be anti-nuclear. Perhaps this has at least a sub-conscious effect on the answer given.

The local newspapers reported that Jim Rogers was in the audience for my talk. Rogers was the CEO of Duke Energy, one of the largest utilities in the country. Jim Rogers was the bête noire of Jim Warren. For years Warren had been hammering Rogers in the media and filing one legal action after another against Duke, trying to stop construction of new coal plants or new nuclear power plants, or close existing ones, arguing instead for programs in energy efficiency. Warren suggested that I write to Rogers, informing him of our newest science results, which indicated that we needed to reduce emissions rapidly. I did write to Rogers, appealing to him, as one of our "captains of industry," to help lead the country to declining emissions, and I offered to help organize a workshop with leading experts in climate science, energy efficiency, renewable energy, nuclear power and carbon capture and storage.

Rogers responded positively, suggesting that we meet to talk about the suggested workshop. We met over a 3-hour dinner in New York (Rogers was every bit the Southern gentleman as his bête noire, Warren). We concluded that the workshop would be more useful if it included other utility CEOs. I had already met Ralph Izzo, CEO of PSEG (Public Service Electric & Gas), having given a talk to him and his senior staff. We agreed that I would contact Lew Hay, CEO of FPL (Florida Power and Light). All three CEOs agreed on the merits of the workshop, which was held in Washington just before the 2008 election.

The principal upshot from the workshop was the conclusion that contributions from all of the candidates, efficiency, renewables, nuclear power, and carbon capture probably would be needed to achieve the rapid emission reductions that climate science showed was needed. That did not mean all candidates were equally likely to be effective, but they all should be given a fair chance. Rather than the government choosing winning technologies, it would be more effective to have a carbon tax or fee. The government should provide assurance that the rate would rise and some indication of how fast, but it would be better if the government did not hamstring the utilities with requirements for use of specific technologies.

Australia. By the time I visited Australia in early 2010 I had concluded that it was wrong to say nothing about nuclear power. Thus, I advocated that it was important to keep nuclear power as an option for places where it made sense. Some countries may be able to phase off fossil fuels rapidly without nuclear power, but others, such as China, likely would need nuclear power.

My main talk in Australia, in Sydney, after I had made comments in support of nuclear power in Melbourne, was picketed by anti-nuclear people handing out leaflets criticizing my position. I spoke with one of the picketers. She was a devotee of Helen Caldicott, an Australian physician who asserts that enormous numbers of people have been killed in nuclear accidents. Caldicott also claims that nuclear accidents have caused a huge number of birth defects.

My Australian hosts told me that Caldicott seemed to make up numbers out of thin air. They told me about a debate in which a physicist pointed out the inconsistency between her claims and numerous international studies. They said that her response (I don't have an exact quote) was in effect: well, who are you going to believe, a medical doctor or a physicist?

I'm a physicist, but that's not what bothers me about the statement. Conclusions should not be based on "belief". They must be objectively drawn from scientific evidence - no need to be more specific because in 2011 the respected British journalist George Monbiot incisively investigated Caldicott's assertions and her sources. Monbiot's article, titled "Evidence Meltdown", began:

"Over the past fortnight I've made a deeply troubling discovery. The anti-nuclear movement to which I once belonged has misled the world about the impacts of radiation on human health. The claims we have made are ungrounded in science, unsupportable when challenged and wildly wrong. We have done other people, and ourselves, a terrible disservice."

I attach Monbiot's entire article, which is just over two pages long.

The most deeply troubling aspect of this matter, from my perspective, is the difficulty and complexity of any effort to inform the public about actual scientific evidence. Public perceptions, which may have been partly spurred by the swinging and swaying in Central Park, are now deeply entrenched in the environmental community. Several environmental groups are dedicated to anti-nuclear positions, many of them including a staff position for a scientist (see Hama-Hama-Hama below) who serves to counter any pro-nuclear actions in the outside world.

The media do not help. CNN's Anderson Cooper (who Anniek and I admire -- his compassion for people and nature is apparent in his reporting), after Fukushima, showed a deformed rabbit born in Japan (it may have had an extra leg, I don't remember) saying something like "we do not know whether this deformity was caused by nuclear radiation from Fukushima…". What we do know is that there is no evidence of an increase in birth deformities. Talk about irresponsible reporting, almost designed to scare the dickens out of people and amplify nuclear concerns!

I continually receive e-mails or letters, very polite, usually beginning with praise for my climate work, but then begging me to stop making any positive statements about the potential for nuclear power to help solve the climate problem. All, or almost all, of these messages are from women. My "theory" for this anomaly is that women are more programmed than men to protect the young. If a mother gazelle hears suspicious rustling in the grass, she may not wait for proof that it is a predator before either moving her young or trying to draw the predator into pursuit of her.

I think this experience provides a partial insight about why, despite a recognized growing need to phase out fossil fuels, nuclear power continues to be shunned. Surely other scientists face similar pressures to stay mum on the subject. I also have the strong impression that the chances of obtaining research funding from foundations, which generally have an environmental bent, is significantly reduced if one makes statements that are viewed as pro-nuclear power.

The con job. Quantitative data on effects of fossil fuel pollution and nuclear radiation yield a startling conclusion. Given that coal pollution alone has been killing more than one million people per year in China for the past half century; Given that the World Health Organization reports well over one million additional annual deaths in the world from fossil fuel pollution; It follows that in a single day more than 5,000 people are killed by fossil fuel pollutants (Fig. 14).

Thus yesterday, in a single day, more people were killed by fossil fuel pollutants than have been killed by all the nuclear accidents in history. Today, in a single day, more people will be killed by fossil fuel pollutants than have been killed by all the nuclear accidents in history. Tomorrow, in a single day, more people will be killed by fossil fuel pollutants than have been killed by all the nuclear accidents in history. But there are no concerts in Central Park to protest. Amazing.

A large fraction of the deaths, and a much larger number of health problems in children and adults, are caused by pollution from coal-fired power plants. The coal-fired energy could have been supplied by advanced generation nuclear power, using technology much improved and safer than the technology of last century, which itself had a sterling safety record. Not to mention that such energy would also have allowed our children and grandchildren the possibility of a stable climate, climate that would also allow other life on the planet to continue to thrive.

We have only ourselves to blame. How could we have done this to ourselves and our children? In my opinion, we pulled on ourselves the biggest con job in the history of planet Earth. We are both the con artist and the con victim.

Hama-Hama-Hama Oil and Gas Corporation

Sophie, do you remember a few years ago, when Jake was just beginning to talk? I was having a discussion with your father and your uncle Erik in which I used the nonce word hama-hama-hama, which I had made up. Jake heard the word and repeated it as he was running around the dinner table. We all laughed. Then, while still running around, he said hama-hama-hama? and hama-hama-hama! We all laughed some more -- I don't think that I completed my discussion.

What I was talking about was my frustration in trying to get political leaders to understand improved nuclear power capabilities. Although the topic could be brought up with them, it seemed that they would later receive quite contrary advice from so-called experts. I soon realized that the experts' advice to them sounded to their ears something like this: hama-hama-hama -- radiation! -- hama-hama -- dangerous! -- hama-hama -- plutonium! -- hama-hama -- dangerous! -- hama-hama-hama. Most of the words were not understandable to the politicians, but they got the message: nuclear power is dangerous.

What I learned was that several environmental organizations each had a nuclear "expert" who would jump in and provide free expertise to politicians or wherever needed. Invariably the advice was anti-nuclear. That was their job. Why the organizations were anti-nuclear varied. Some had long been anti-nuclear because of conflation of nuclear power with nuclear war. Others became anti-nuclear in response to the Three-Mile-Island accident.

In any case, the experts were not acting as scientists. As Feynman made clear, science demands that you reexamine your conclusions with an open mind when new data or information becomes available. However, the experts had a prescribed position to defend. Once an organization has a prescribed position and is receiving donations to lobby for that position, it becomes very difficult for them to act as a scientist with an objective open mind.

Once by chance I met the nuclear expert of a large environmental organization. I tried to inform him of the capabilities of a "fast" nuclear reactor. At first he was positive as I described its ability to utilize nuclear waste as fuel, but finally he realized that I was talking about something he was programmed to oppose -- he said "that's a breeder!" It soon became clear that he was not a real nuclear expert. Breeder has been converted by the anti-nuke community into a bad word.

Closing the fuel cycle inherently means that we "breed" useful nuclear fuel from nuclear material that is unusable in old generation reactors. That includes nuclear waste, excess weapons material, and "depleted" uranium, which needs to be enriched in appropriate uranium isotopes to make it "burnable". Anti-nukes, with the help of a lot of hama-hama-hamas, want you to believe that breeding allows opportunities for rogue nations or terrorists to acquire nuclear material, but real experts in fast reactors are doing everything they can to reduce such dangers. Already they have reached a point such that fast reactors would be a more difficult route for rogue/terrorists to pursue than other existing routes to nuclear material. Multiple routes to nuclear material exist in many nations. Thus, for the time being, there must be international cooperation in tracking the activities of rogue nations and in making nuclear technology such that it is as difficult as possible for terrorists to make use of it. Perhaps later this century we will have found a practical bountiful source of clean energy without the side effects of our present options. For example, nuclear fusion, the process by which our Sun converts hydrogen to helium, is still being pursued. In such case, the dream of expelling nuclear fission from the planet might become conceivable.

In the mean time, the responsible thing for the United States to do is to exercise leadership, not stick its head in the sand and pretend that nuclear energy is disappearing from the planet.

What I have learned from discussion with anti-nukes is that their goal is not that we produce safer nuclear reactors -- their goal is elimination of nuclear power from the planet. Therefore, although they come up with technical objections to any new proposal, in fact no changes to the proposal would satisfy them. The reason that "fast" reactors scare the dickens out of them seems to be that such technology would provide us an inexhaustible fuel supply. Their goal is that renewables, such as the sun and wind, should supply all of our energy.

Amory Lovins and Others. Amory Lovins is a brilliant and wonderful person. He is also the best salesman I have ever met. Amory is an extremely generous person -- he not only answers questions that you might send him, he answers comprehensively with a remarkable level of detail. Amory has received far more awards than anybody that I know. He deserves them all.

I met Amory a few decades ago. Energy efficiency was then and still is his strongest suit. Everybody agrees that efficiency, negawatts as Amory calls it, should have highest priority. Every energy source causes some environmental impact, so the most helpful thing we can do is cut our energy demand. Amory argued that "barriers to efficiency" are the biggest problem. If the government would just remove those barriers, he said, business people would snatch up the hundred-dollar bills that are lying all over the ground. Amory has a very good point, and he can list dozens of barriers that should be removed.

Surely Amory is right about the priority that should be given to efficiency. However, I suggest that the most effective way to unleash efficiency is via an overarching transparent economic incentive. In view of our need to solve the climate problem, the proper economic incentive is a rising fee on carbon. If it is collected at the source, the domestic mine or port of entry, it will cover everybody: businesses, consumers, governments. Fossil fuels can come into the price of products in many complex ways, but they are all captured properly if a flat across-the-board carbon fee is collected at the source. A rising fee also brings the myriad of efficiency barriers under scrutiny, making it more likely they will be addressed.

Lovins argues that our energy needs can be met without any fossil fuels, without nuclear power, without large hydroelectric power, and without a carbon tax or fee. When I first read this, I had the feeling that he may be "playing to the crowd," in effect telling the audience everything they want to hear. Such a tendency would be related to my hesitation to clearly answer questions about nuclear power from environmentally-oriented audiences. There is also possible pressure from a desire not to offend any potential financial supporters of one's research organization.

However, I have spoken with Amory several times in the past decade and I am persuaded that he fervently believes all of his assertions. He believes energy efficiency and "soft" energies can handle all energy requirements. Soft energies are defined to include solar, wind, and geothermal energies, for example. Of course, even soft energies have some impact on the environment. Windmills, for example, affect the landscape, make noise, and kill birds; and, if they are to be a major energy source, there will also be a need for more cross-country transmission lines to take the energy from where wind is plentiful to where energy is needed. Further, windmill production involves use of rare elements, requiring mining with much local pollution.

Amory has agreed, in private discussions we have had while attending conferences, that a carbon fee may be useful, even though he says it is unnecessary. However, I am very disappointed that he has not come out strongly in public for a carbon fee, and specifically for a fee and dividend, which would drive the efficiency that he advocates, help select economically efficient pathways, and move us as rapidly as possible to a clean energy future.

Amory Lovins has earned his reputation as world energy expert and I am convinced that he is not playing to the crowd in stating his belief that all of fossil fuels, nuclear energy and large hydropower can be dispensed with. I am less convinced in the case of some others, scientists and non-scientists, who argue that we do not need fossil fuels or nuclear power.

However, before discussing this further I must disclose a relevant pet peeve. I only mention it because of the huge number of e-mails and letters that I get on the energy/climate topic. It is impossible to answer each of them individually. So I take this opportunity to clarify the matter, so they may understand why I do not answer. It is related to the Boatload Method.

Boatload Method. This method is used after a person decides on his answer for an issue. The approach is to shower others with a boatload of related data. The aim seems to be persuasion that one is an expert on the matter and thus the proposed answer is probably correct.

There is a Corollary to the Boatload Method, developed or at least perfected by the Hama-Hama-Hama boys. The Corollary is that it is not a bad idea to throw in some words or data that the listener probably won't understand. This further persuades the listener of one's expertise.

For example, there are scientists who insist we do not need fossil fuels or nuclear power. They usually start with that answer; they assume that all-renewables is the optimum energy system. Then they set out on a sales job, with the Boatload Method as a sales technique.

Example #1: they know that providing all the world's energy from only diffuse energy sources is problematic. So one number they give is the area required to collect this energy (with solar panels or windmills, for example); they show that the area is small compared to the country or state considered. However, the area required is large and may be unacceptable to much of the public. Moreover they minimize this required area via dubious assumptions about how fast energy efficiency will improve in all nations. The energy provided via their assumptions is much less than what most economists say is needed if we hope to reduce or eliminate global poverty.

Example #2: They point out that most of the new energy sources installed in the United States in a recent period were renewable energies. They want us to infer that renewables are taking over and will allow us to phase out fossil fuel use. They may not point out that the numbers are small at a time of little growth in U.S. energy use, or that the growth of renewable use was subsidized and largely a result of laws that required increased renewable energy use.

Example #3: When I noted that the proportion of France's electricity coming from carbon-free nuclear power increased in one decade from 8 to 77%, one of many responses was: yes, but the French increased their oil use by driving a lot. That's pretty irrelevant, but I say let them drive -- a beautiful country to drive in -- but they need to move to electric vehicles or vehicles powered by a liquid fuel made from carbon-free energy. They will need a lot of carbon-free electricity.

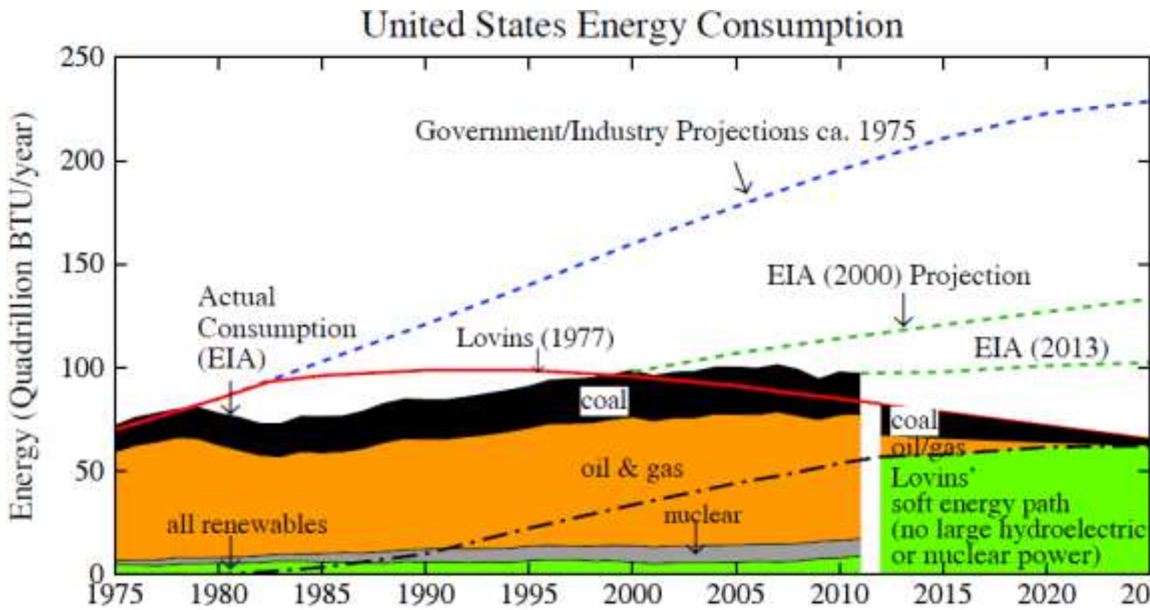

Fig. 15. United States energy consumption [*U.S. Energy Information Administration, Annual Energy Outlook 2013*]**.**

There are hundreds of such numbers that can be debated. It is analogous to the situation with climate change, where climate deniers bring up a boatload of technical details. They may be honest people, but they get bogged down in these and fail to see the forest for the trees.

Scientific Method. The scientific method requires continual objective reassessment of conclusions as new data becomes available. Richard Feynman emphasized that it is easy to fool people, and, he said, the easiest person to fool is yourself. There is a human tendency to focus on the numbers that support one's belief. Climate deniers, for example, look at a myriad of data and cherry pick numbers that they think support their beliefs. We must be able to see the forest for the trees. For example, we gain global insight by looking at the planet's energy balance and also from how the planet responded to energy imbalances during Earth's history.

Similarly, it is helpful to look at overall energy data, for the world and individual nations. U.S. energy consumption (Fig. 15) increased only moderately in the past 40 years, since the oil price shock of 1973 finally put an end to rapid exponential growth. Energy use continued to increase, but only at about 1%/year, much less than government projections. In the past several years U.S. energy use declined modestly, at least partly due to economic recession, but also with the help of improved energy efficiency. Indeed, energy use has been much closer to what Lovins projected in the 1970s rather than government projections, which seem to always assume energy growth.

On the other hand, Lovins' projection of "soft energy" growth has proven to be unrealistic despite renewable energies receiving the largest subsidies per unit energy of all energy sources. Actual renewable energy provides a significant part of U.S. energy use (green area on left in Fig. 15), but most of the renewable energy is from hydropower, not solar, wind and geothermal energies.

In view of the data in Fig. 15, and even more importantly the data in Figs. 11, 12 and 13, the scientific method demands reassessment of conclusions, especially in view of the emerging urgency of addressing climate change. Yet Lovins' response has been to double down on his long-standing assertion that global movement onto a soft-energy pathway is just around the corner. His new book, "Reinventing Fire", is the epitome of the Boatload Method, a collection of fine write-ups by Rocky Mountain Institute staff members. The most telling pieces in the book are the two Forewards by the President of Shell Oil and the Chairman and CEO of Exelon Corporation; I recommend reading both of those.

The energy data do not mean we should give up on the possibility of renewables providing a large part of our energy. We should get as much as we can from them, and it is realistic to expect their contribution to grow over time. I strongly support that goal. As you know, our solar panels, averaged over the year, generate twice as much electrical energy as we use.

However, it would be foolish to assume that renewables alone will move us off fossil fuels, especially at the required rate of phasing down fossil fuel emissions. We should support having all hands on deck. Let all carbon-free energies and energy efficiency compete in the marketplace with a rising carbon fee. Choices will differ from state to state and nation to nation.

Some of the renewable energy advocates are chief contributors to the hama-hama-hama anti-nuclear advisory activity, which has led the U.S. government down a path that has barely tolerated research and development on nuclear power. Renewable energy advocates may feel that by preemptively cutting off the nuclear power option they increase the likelihood that renewable use will match their projections, given the present lack of other non-carbon alternatives. That is a pretty small benefit compared with the cost of having greatly increased the likelihood that young people will have to deal with climate change spiraling out of their control.

The attacks on nuclear power by renewable advocates are harmful. What if renewables are unable to rapidly replace fossil fuels (a conclusion most energy experts say is nearly certain)? We need alternatives. We should not exterminate any clean energy alternatives a priori.

Hama-Hama-Hama Oil & Gas Corporation. We, citizens in the United States and in the world as a whole, are in the process of taking the first steps onto an energy pathway such that declining conventional oil and gas and increasing global energy demand will be met largely with budding unconventional fossil fuels as well as expansion of conventional drilling into deeper waters and into pristine regions such as the Arctic. We are doing this despite the fact that it is now crystal clear that we cannot burn these unconventional fossil fuels and all remaining coal without guaranteeing that young people and future generations face a future of deteriorating climate with widespread human suffering, increasing scarcity of water in many regions, evisceration of natural landscapes, and decimation of the spectacular life on our planet.

It is not too late to avoid that path. There are substantial economic benefits of an alternative course, in addition to the practical and spiritual benefits of preserving what some call creation and others call nature. However, we surely will follow the path of unconventional fossil fuels and burning massive coal amounts, if we do not wake up to reality. People claiming that the world is moving to all renewables and efficiency are not facing up to what is actually happening. If we allow the delusion to continue to reign, the delusion that we are on a path to all renewables, what we actually get will be a future of growing hydrofracking for gas and oil, with increasing environmental destruction as the mining goes to greater depths and less productive areas. Not only tar sands, but tar shale will be massively developed. We will have only ourselves to blame as we become customers of the Hama-Hama-Hama Oil & Gas Corporation.

If the broad energy perspective provided by Figs. 11-13 and 15 is not persuasive of where we are headed, look at our political leaders. They mouth the words of environmentalists, but they know they cannot allow the lights to go out, they cannot allow the fuel supply for our vehicles to stop. Thus President Obama, despite recognizing the reality of climate change and saying that we have a planet in peril, approves more drilling off-shore and on public lands, praises hydrofracking, and does not try to stop mountaintop removal or destructive long-wall coal mining.

Further confirmatory insight into the reality of energy directions is provided by energy investments. A few years ago, a major oil company invited me to speak at a meeting of their executives. Over coffee at a meeting break I asked an oil executive about plans for investment in renewable energies. He said it was small, negligible on their balance sheet. I pointed out, with a smile, the prominence of windmills and solar panels on their television advertisements. His response, I suppose, could be characterized as either a smile or a smirk. I think it was a smirk, an indication that the oil industry is very happy to play along with a delusion.

The delusion is that we are on a track to replace fossil fuels and nuclear power with renewables. In reality we are moving mainly to temporarily cheap fracked gas and unconventional oil. Gas is replacing coal at power plants. Yankee nuclear power plant, now providing 70% of Vermont's electricity and exporting power to other states, will be closed. Vermont's government decided it did not want the least cost electricity (nuclear), instead taking a modicum of higher cost wind and solar energy and much more gas at a variable price that will be rising. Such is the power of irrational fear stoked by the Central Park rally and the Hama-Hama-Hama boys. The Yankee nuclear power plant article concludes: Now when children ask, "Why do I have to do my homework?" parents can point to Vermont and say "That's why!" [eliminate paragraph?]

If a smirk is not meaningful information to you, perhaps $23 trillion gets your attention. That's the amount of money, according to the International Energy Agency, that the fossil fuel industry plans to invest in new fossil fuel extraction and processing during the next two decades. A growing fraction of that will go into unconventional fossil fuels. These total investments in increasingly carbon intensive fossil fuels dwarf all planned investments in renewable energies.

Michael Klare describes the energy path we are on in "America's Green Energy Future is a Pipe Dream." But Klare does not say how to get off that path, how we can avoid becoming customers of the Hama-Hama-Hama Oil & Gas Corporation, the purveyors of unconventional fossil fuels.

How Can We Get onto a Sensible Energy Path?

We have wasted time and missed opportunities. As a result, it is nearly impossible to hit the 500 GtC target for fossil fuel emissions. However, that does not mean we should give up, and we certainly should not accept 1000 GtC as a reasonable target.[26] It will make an enormous difference whether eventual emissions fall closer to 500 GtC or 1000 GtC.

[26] Just as I feared, some governments assume a 2°C target for global warming is fine and interpret that as allowing fossil fuel emissions of at least about 1000 GtC. I was in Norway in August, where the government was using these goals as a cover to open up more areas in the Arctic for drilling and to develop tar sands in Canada.

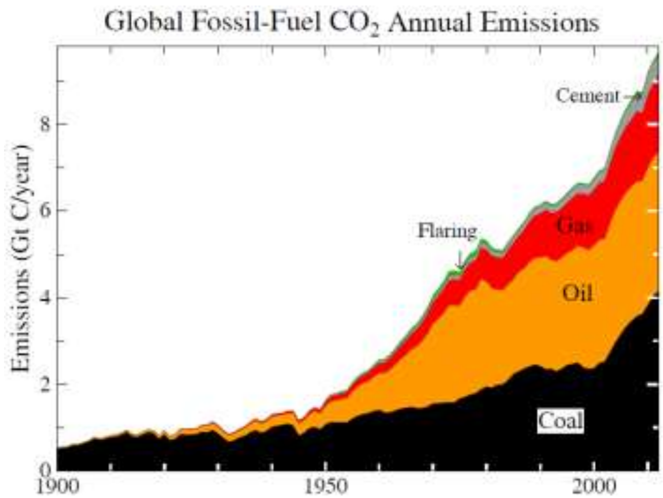

Fig. 11. CO_2 annual emissions from fossil fuel use and cement manufacture.

The most important thing that we must do, by far the most important, is institute a rising fee on carbon, collected at the fossil fuel source so that it covers all activities across-the-board. I have already discussed this several times and written an entire letter to you on it. Therefore, I will not belabor it further, except to make one observation about unconventional fossil fuels.

A rising carbon fee will quickly affect the viability of tar sands and tar shale, because they are so carbon intensive. That is why stopping construction of the Keystone XL pipeline is so important. If it is stopped and a rising carbon fee is adopted, tar sands never will be substantially exploited.

The data expose another green pipe dream. Fig. 11 is so important that I repeat it here. Fig. 11 shows that increased coal use is responsible for the rapid rise of global fossil fuel emissions. Increased coal use is mainly in China, where coal is the principal fuel for power plants.

Coal use to generate electricity in China is a problem for global climate but also an opportunity for the world to take a huge step down the path that we must get on to preserve our planet and the future of young people. Fortunately, in a sense, this coal use in China is a problem in several different ways. The local air pollution is becoming unbearable, so unhealthful that it threatens to cause the evacuation from China of some of its most valued citizens. The pollution harms neighbors, including Korea and Japan, and the deposition of mercury on the ocean will affect all nations that consume fish from the sea. There are thus many reasons why China and the global community wish to see the coal emissions problem solved. The most important reason is the huge contribution of coal use in China to current CO_2 emissions and thus global climate change.

The green pipe dream is that China will replace their coal-fired power plants with renewables. China is a leader in producing solar panels and windmills and many are being installed in China. However, they do not replace coal-fired power plants used for baseload electricity and they are not even preventing the construction of new coal-fired power plants. If the coal boilers are to be replaced rapidly it will be with an alternative source of continuous baseload energy that can use the same electricity distribution system, not distributed sources of intermittent energy.

There are two candidates to replace coal-fired boilers: a gas-fired unit or modern nuclear power. Gas is no long-term solution. It would lead to expansion of fracking and other unconventional

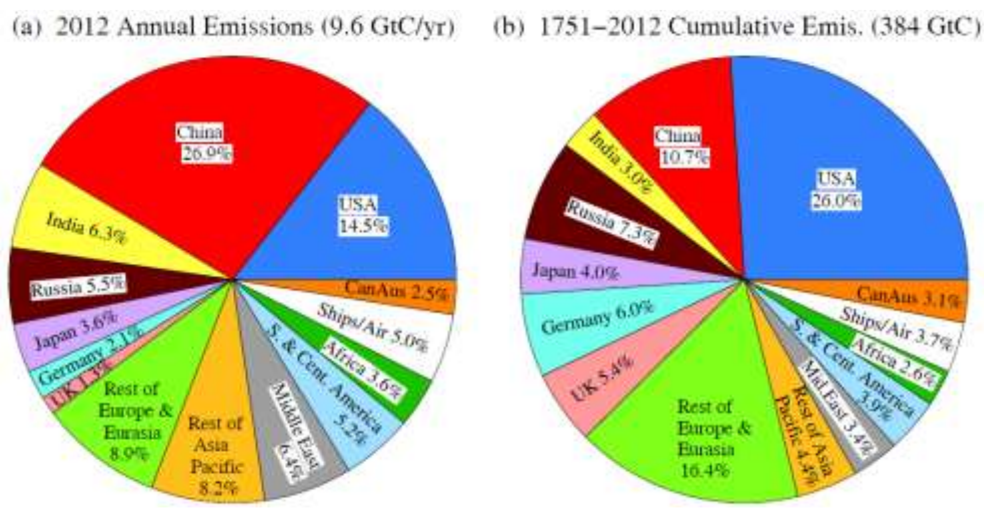

Fig. 16. Fossil fuel CO_2 emissions in 2012 (a) and cumulative (b). Emissions include gas flaring and cement manufacture, these processes increasing cumulative emissions from 370 to 384 GtC.

sources of gas, which cannot be tapped if climate is to be stabilized. Fortunately, progress in development of simplified, safer, more modular nuclear power plants has continued, in large part in the United States, despite efforts of anti-nukes to suppress the technology and their partial "success" in slowing down nuclear technology development.

Why would the United States and China cooperate in replacing China's dirty coal-fired boilers with modern modular nuclear units? Lots of reasons, starting with those implied by Fig. 16. China and the United States are responsible for about 40% of global fossil fuel CO_2 emissions. Climate change is proportional to cumulative emissions (Fig. 16b), so the United States bears more responsibility than any other nation for climate change. However, the solution lies in reducing current emissions and that requires, most of all, actions in China.

The main reason for cooperation is that the United States and China are on the same boat and will suffer similar fates if the boat begins to sink. Both nations are in the cross-hairs of climate change, highly vulnerable to shifting climate zones, increasing climate extremes, and rising seas.

Besides such cooperation will be beneficial to both nations from their economic perspectives.

This letter is already too long. I will describe the plans for modern safe nuclear power plants in my letter on nuclear physics. I just note here that there is widespread agreement that the future of nuclear power lies with small modular reactors, with the basic elements built in an assembly-line process in a factory and shipped to the power plant location. A large power plant would use several of these reactors on the same site. This approach has the potential for rapid construction and low cost, for both light-water reactors and fast reactors that can burn nuclear waste.

These concepts are discussed on the American Atomics web site. I doubt that they can find financing, unless investors see a rising carbon fee. Bill Gates is funding development of a fast reactor, via TerraPower, but they are on an almost decade-long slow track. The quickest route to a fast reactor is probably General Electric's PRISM reactor, a 300 Megawatt reactor that has its origins in the Argonne National Laboratory work that Clinton tried to terminate in 1993.

American Atomics vision is an assembly plant in Detroit, creating an industry that could repower that city with good paying jobs. It is difficult to see how that could be done rapidly, given the molasses-pace that has developed in the U.S. Nuclear Regulatory Commission approval process, but it would be great to see somebody try. In the meantime, however, what is needed is a high level decision for international cooperation. The task of replacing China's coal plants is small in comparison with the huge industrial effort that was spun up in just a few years at the onset of World War II. The cooperation potentially could be most effective if it involved South Korea (and perhaps Japan), which has skilled labor with budding modern nuclear capability.

Cooperation among these nations would make it possible to rapidly phase out most of the global CO_2 emissions from coal, which are approaching one-half of total global CO_2 emissions. U.S. cooperation is important, given its technology leadership and the constraints imposed by existing nuclear agreements with South Korea and other nations. The largest obstacles to achievement of an agreement are probably in the United States.

That obstacles can be described as a pyramid. At the bottom is a minority, but vocal, public opposition to nuclear power. The middle level is several organizations, mostly environmental organizations, but also others such as the Rocky Mountain Institute, which have vigorously lobbied against nuclear power. At the top are a handful of Hama-Hama-Hama boys, who have carried out the lobbying, including, as discussed above, much misinformation.

Normally, in such situation, the fastest route to change would be at one of the higher levels in the pyramid. That is unlikely in this case because the pyramid top has a vested interest, indeed a conflict of interest via there longtime advocacy and interest in renewable energies. Some of the organizations, such as the Union of Concerned Scientists, have relaxed their nuclear opposition as the climate emergency emerged, but their statements are too wishy-washy to be much help.

Therefore, the best chance for action probably depends on the public. Remarkably, despite longstanding vocal anti-nuclear activities, an often irresponsible media, and the unfortunate timing of the Fukushima accident, a majority of the American public still supports nuclear power. I believe this is a testament to the common sense of the public. However, as has been obvious in recent years, Washington and Congress are very capable of ignoring the public and responding to special interests. It requires effort to make democracy work.

Government Failure & Public Pressure

The task is staggering. We have a world-wide failure of governments to act responsibly and protect the rights of citizens, especially young people. Despite unambiguous scientific evidence that fossil fuel emissions must be phased down rapidly to avert growing catastrophic climate impacts, governments continue to allow and encourage efforts to extract all fossil fuels that can be found. Even governments or parties recognizing the threat propose only ineffectual actions.

What actions should citizens take in democracies to try to rectify government failure? The organization [350.org](350.org) is operating in every nation of the world except North Korea, bringing growing awareness of the matter and appropriately involving young people. They are making a special effort to prevent approval of the Keystone XL pipeline, which is particularly important because the pipeline is an attempt to mainline an addiction to the dirtiest fossil fuel on Earth.

The most essential government action is initiation of a carbon fee, with the money distributed uniformly to the public so as to affect consumer choices and lifestyle changes, and to spur entrepreneur and business innovations. Carbon fee and dividend in this effective form is unlikely to occur without public pressure. Tax-and-spend liberals always want to grab some of the money to make the government bigger (under the guise of "paying off the national debt") and to specify that funds be spent on ideologically-driven technology choices. Conservatives can recognize the merits of the revenue-neutral method of improving economic efficiency, but many conservatives (and liberals) are on the payroll of the fossil fuel industry (via "campaign" contributions and lobbying jobs post-government) leading even to denial of climate change.

Despite these formidable odds, progress is being made in gaining support for a revenue neutral fee-and-dividend approach, led by CitizensClimateLobby.org. CitizensClimateLobby is highly respected as it uses the democratic system in a respectful, polite, persistent way via repeated visits with members of both political party, op-eds, letters-to-the-editor, and public presentations. CitizensClimateLobby is rapidly growing volunteer organization. They could effectively use financial contributions to support administration of a rapidly growing volunteer organization.

Here is a way that people could advance the prospects for preserving our climate and nature while saving money. Stop providing any support for environmental organizations that have an anti-nuke agenda. Better yet stop providing any support and send them a letter stating that you will not consider future support until they desist from their anti-nuke agenda. We need all green energies to be on the same side. I will not list specific organizations now, but I will in the future after I have checked there latest position. Although most of them are sclerotic and have been in Washington too long (becoming political), it is always conceivable that some leaders may have an open scientific mind.

Update on Butterflies, Bluebirds and Bats (and Jeremiah)

Sophie, sorry this letter ran out of control on me. I threw in lots of topics corresponding to those in a long technical paper that I am just finishing. I was in a big hurry writing it, so I did not yet have time to think how to make the topics more accessible and more letter-like. I'm in a hurry because of upcoming meetings, and I may make a second trip to Europe regarding the tar sands. The Canadian government, not representative of Canadians in my opinion, is going all out to hook the U.S. on their opium with a mainline right to our heart. They seem to be desperate, the way they are putting pressure on Europe. I wonder if their support of Obama's desire to bomb Syria is, at least partly, a bribe to him.

Evidence Meltdown

The Guardian 5 April 2011

The green movement has misled the world about the dangers of radiation.

By George Monbiot

Over the past fortnight I've made a deeply troubling discovery. The anti-nuclear movement to which I once belonged has misled the world about the impacts of radiation on human health. The claims we have made are ungrounded in science, unsupportable when challenged and wildly wrong. We have done other people, and ourselves, a terrible disservice.

I began to see the extent of the problem after a debate last week with Helen Caldicott(1). Dr Caldicott is the world's foremost anti-nuclear campaigner. She has received 21 honorary degrees and scores of awards, and was nominated for a Nobel Peace Prize(2).

Like other greens, I was in awe of her. In the debate she made some striking statements about the dangers of radiation. So I did what anyone faced with questionable scientific claims should do: I asked for the sources. Caldicott's response has profoundly shaken me.

First she sent me nine documents: newspaper articles, press releases and an advertisement. None were scientific publications; none contained sources for the claims she had made. But one of the press releases referred to a report by the US National Academy of Sciences, which she urged me to read. I have now done so – all 423 pages(3). It supports none of the statements I questioned: in fact it strongly contradicts her claims about the health effects of radiation.

I pressed her further and she gave me a series of answers that made my heart sink – in most cases they referred to publications which either had little or no scientific standing, which did not support her claims or which contradicted them. (I have posted our correspondence(4a,4b), and my sources, on my website). I have just read her book Nuclear Power is not the Answer(5). The scarcity of references to scientific papers and the abundance of unsourced claims it contains amaze me.

But it gets worse; much worse. For the past 25 years, anti-nuclear campaigners have been racking up the figures for deaths and diseases caused by the Chernobyl disaster, and parading deformed babies like a mediaevel circus. They now claim that 985,000 people have been killed by Chernobyl, and that it will continue to slaughter people for generations to come. These claims are false.

The UN Scientific Committee on the Effects of Atomic Radiation (Unscear) is the equivalent of the Intergovernmental Panel on Climate Change. Like the IPCC, it calls on the world's leading scientists to assess thousands of papers and produce an overview. Here is what it says about the impacts of Chernobyl.

Of the workers who tried to contain the emergency at Chernobyl, 134 suffered acute radiation syndrome; 28 died soon afterwards. Nineteen others died later, but generally not from diseases associated with radiation(6). The remaining 87 have suffered other complications, included four cases of solid cancer and two of leukaemia. In the rest of the population, there have been 6,848 cases of thyroid cancer among young children, arising “almost entirely” from the Soviet Union’s failure to prevent people from drinking milk contaminated with iodine 131(7). Otherwise, “there has been no persuasive evidence of any other health effect in the general population that can be attributed to radiation exposure.”(8) People living in the countries affected today “need not live in fear of serious health consequences from the Chernobyl accident.”(9)

Caldicott told me that Unscear’s work on Chernobyl is “a total cover-up”(10). Though I have pressed her to explain, she has yet to produce a shred of evidence for this contention.

In a column last week, the Guardian’s environment editor, John Vidal, angrily denounced my position on nuclear power(11). On a visit to Ukraine in 2006, he saw “deformed and genetically mutated babies in the wards … adolescents with stunted growth and dwarf torsos; foetuses without thighs or fingers”. What he did not see was evidence that these were linked to the Chernobyl disaster.

Professor Gerry Thomas, who worked on the health effects of Chernobyl for Unscear, tells me that there is “absolutely no evidence” for an increase in birth defects(12). The National Academy paper which Dr Caldicott urged me to read came to similar conclusions. It found that radiation-induced mutation in sperm and eggs is such a small risk “that it has not been detected in humans, even in thoroughly studied irradiated populations such as those of Hiroshima and Nagasaki.”(13)

Like John Vidal and many others, Helen Caldicott pointed me to a book which claims that 985,000 people have died as a result of the disaster(14). Translated from Russian and published by the Annals of the New York Academy of Sciences, this is the only document which looks scientific and appears to support the wild claims made by greens about Chernobyl.

A devastating review in the journal Radiation Protection Dosimetry points out that the book achieves its figure by the remarkable method of assuming that all increased deaths from a wide range of diseases – including many which have no known association with radiation – were caused by the accident(15). There is no basis for this assumption, not least because screening in many countries improved dramatically after the disaster and, since 1986, there have been massive changes in the former eastern bloc. The study makes no attempt to correlate exposure to radiation with the incidence of disease(16).

Its publication seems to have arisen from a confusion about whether the Annals was a book publisher or a scientific journal. The academy has given me this statement: “In no sense did Annals of the New York Academy of Sciences or the New York Academy of Sciences commission this work; nor by its publication do we intend to independently validate the claims made in the translation or in the original publications cited in the work. The translated volume has not been peer-reviewed by the New York Academy of Sciences, or by anyone else.”(17)

Failing to provide sources, refuting data with anecdote, cherry-picking studies, scorning the scientific consensus, invoking a cover-up to explain it: all this is horribly familiar. These are the habits of climate change deniers, against which the green movement has struggled valiantly, calling science to its aid. It is distressing to discover that when the facts don’t suit them, members of this movement resort to the follies they have denounced.

We have a duty to base our judgements on the best available information. This is not just because we owe it to other people to represent the issues fairly, but also because we owe it to ourselves not to squander our lives on fairytales. A great wrong has been done by this movement. We must put it right.

www.monbiot.com <http://www.monbiot.com>

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7. Para 33, page 8 and para 4, page one. As above.

8. Para 99, page 19. As above.

9. Para 100, page 19. As above.

10. http://www.democracynow.org/2011/3/30/prescription_for_survival_a_debate_on

11. http://www.guardian.co.uk/commentisfree/2011/apr/01/fukushima-chernobyl-risks-radiation

12. Professor Gerry Thomas, Chair in Molecular Pathology, Department of Surgery & Cancer, Imperial College, London, pers comm, 1st April 2011.

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16. The authors announce that they reject this method in the introduction to the book. Alexey V. Yablokov, Vassily B. Nesterenko and Alexey V. Nesterenko, as above, page 2.

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