Fire on Planet Earth

11 December 2019

James Hansen

California fires are a minuscule piece of global change that will sweep through our planet this century and beyond, and the role of humans in the fires is debatable. Yet the fires are symbolic, an apt metaphor for consequences of global warming, if we do not alter our planet's course.

I am concerned that, despite all the recent publicity about climate change, the public and policy-makers are not well-informed about the implications of climate change for energy policy.

I have a reputation for bluntly speaking truth to power, but for the last few years I minimized comments on energy policy, other than advocating a rising carbon fee & dividend. My rational: the only way I can make the basis for my conclusions really clear is to finish *Sophie's Planet*.

The book is taking longer than planned, because of the need to do some science and write a science proposal. Now we enter an election year. I tried, but failed, to influence politicians and public opinion in the past. However, in a democracy, it is essential to keep trying.

Today, the potential enormity of the consequences, if we fail to communicate well the policy implications of climate change, demands that we ignore personal and institutional backwash.

Friends advise me that my assessment conflicts with deeply felt beliefs and might be interpreted as being critical of iconic individuals, which will make it difficult to obtain financial support for our group, Climate Science, Awareness and Solutions (CSAS). I hope that is not the case.

Analysis of energy and climate is a many-faceted scientific problem, which demands rigorous use of the scientific method[1] to achieve success. The objectivity of the scientific method is crucial if we are to achieve successful national and global energy/climate policy decisions.

[1] The scientific method is described in *Sophie's Planet* as: 1. Study all available data on the matter, 2. Be very skeptical of your interpretation, 3. Honestly reassess from scratch when new data become available, 4. Your preference, your ideology must not affect your assessment.

With less than a year before the upcoming election in the United States, the public has never been more in need of rigorous information on energy and climate.

I hope you will consider making a donation to CSAS this month, as I have only a few weeks to find the support required for Columbia University to renew appointments of the CSAS staff – Pushker Kharecha (expert in carbon cycle and energy), Makiko Sato (physicist and expert in all data), Craig Rye (post-doc, oceanographer), and Eunbi Jeong (program coordinator) -- for the first six months of 2020. Last year we lost the base support for our program (Two Gentlemen), and a recent proposal for long-term support was unsuccessful, but I believe we have reasonable prospects to obtain base support if we have more time.

You can contribute to CSAS directly at https://csas.givenow.columbia.edu/#. This is the easiest and fastest way to give online directly to our program. Alternatively, you can send a check to our office address: Climate Science, Awareness and Solutions, Earth Institute, Columbia University, 475 Riverside Dr. Ste 401-O, New York, NY 10115. Checks should be made **payable to** "The Trustees of Columbia University" and include **a note** on the memo line that the gift is for "Climate Science, Awareness and Solutions." You can find full donation instructions on our giving page: https://csas.earth.columbia.edu/giving. Eunbi (ej2347@columbia.edu) also can provide assistance.

We have information relevant to climate solutions. I can probably communicate the knowledge we have acquired best by describing the path of my own education on the topic. That is the approach I am taking in writing *Sophie's Planet*, and that is the approach that I take in the note below, after some brief comments on the California fires. The note is a little long -- I am sorry that I did not have time to write a briefer one.

Comments on the California fires: Chad Hanson, who is a forest ecologist with the John Muir Project, and I teamed up recently to write an op-ed "Fueling the next Rim fire" in the Los Angeles Times. California received $28 million from the federal government for disaster recovery and rebuilding from the 2013 Rim fire in and around Yosemite National Park.

California, under Governor Gavin Newsom, chose instead to give the money to industry for destructive clear-cutting and planting of artificial tree farms on public and private land. Science has shown that this practice devastates the ecosystem and fuels the most destructive fires. It also reduces storage of carbon in the forest, thus exacerbating global climate change.

In this case of California fires, the science was clear enough. Other political considerations or simple government incompetence or negligence must have come into play.

Global climate change policy today is ineffectual, with potential for tragic consequences. Is this, at least partly, a communications failure? I think so. *Sophie's Planet* includes confession of communication failures. Here I briefly describe a few of these, in hopes of improving the prospects for better results in 2020.

After testifying to Congress in 1988 and 1989, I bailed out of public communication for 15 years. I did not mind the heat,[2] but I expected Mother Nature to provide the most effective response to critics. I was an awkward presenter – I simply read my testimony – and was uncomfortable in interviews. Others were more talented at communication and even enjoyed it. *Science* magazine[3] accurately described me as a "witness" and Steve Schneider as a "preacher."

Besides, the political response to late-1980s concerns about climate change, I argue[4], was as much as could have been hoped for at that time. Almost all nations agreed in 1992 to the United Nations Framework Convention on Climate Change, with the objective to limit greenhouse gas emissions so as to prevent "dangerous anthropogenic interference" with the climate system.

The problem, rather, was that energy and climate policies needed to achieve the Framework's objectives were never adopted. Sure, we can blame the politicians for that. I have called them "well-oiled" and "coal-fired," pointing out the undue influence of the fossil fuel money on our governments. However, the more I dig into the history of what went wrong, the more I also see a role of communications failure about the implications of climate change for energy policy.

The delayed response of climate to forcings (e.g., a change of atmospheric composition) is a problem, because the public is not roused into action until it actually sees climate change effects – and by then, more climate change is "in the pipeline." Moreover, the dominance of amplifying feedbacks in the climate system means that the climate response continues to grow on decade, century and longer time scales. Amplifying feedbacks are the reason climate has huge variability on paleoclimate time scales. *These facts imply that we must slow and partly reverse the human-made changes of atmospheric composition, if we want to avoid cataclysmic climate disruption.*

That message is staggering! The public and policymakers do not appreciate its full implications. The need to reverse some of the existing human-caused atmospheric change, on a time scale that we are now trying to define, has not been accepted by the powers-that-be. True, some of the politicians fronting for those powers make grandiloquent pronouncements, even referring to the "existential threat" posed by climate change. However, they propose policies that are acceptable to the powers-that-be, policies that are practically worthless for addressing the climate crisis.

Politicians are people. Like all people, they are complex. Despite the sub-ten-percent approval rating of Washington, individual politicians are better liked, partly because their empathetic side often shows through, which aids electability. However, they are subject to a crush of pressures to stay in office, as well as political constraints. For example, they are not supposed to change their position – they would be labeled as a flip-flopper – in contrast to scientists, who are taught to reexamine their conclusions when new data appear. That is the story I will tell here.

Like most scientists, I was slow to grasp the ignorance of politicians about the policies needed to address climate change. Scientists were always telling the truth about climate, even

[2] Kerr, R.A., 1989: Hansen vs. the World on the Greenhouse Threat, *Science* **244**, 1041-1043.
[3] Pool, R., 1990: Struggling to do science for society, *Science* **248**, 672-673.
[4] Hansen, J., Saving Earth, 27 June 2019 Communication, www.columbia.edu/~jeh1.

though I suggest that the IPCC (Intergovernmental Panel on Climate Change), almost by its nature, tends to be 5-10 years behind state-of-the-art understanding.

However, scientists were not telling the whole truth. Because they were discouraged from telling the whole story, even explicitly told not to do so. I will get to that matter in a moment.

I was fortunate to join NASA when it was still relatively young and vigorous. I served under a virtual pantheon of stars in science and engineering, people such Tom Young, Hans Mark, Tim Mutch, Noel Hinners, Ed Weiler and many others.

After testifying to Congress in 1989, I avoided media, indulging in what Richard Feynman describes as "the pleasure of finding things out." I concede my privileged position in *Sophie's Planet*. My wife, Anniek, tolerated my inordinate obsession with scientific studies and shouldered most of our parenting and household responsibilities. Meanwhile I had at my disposal a climate model of unusual capability for precise analyses, thanks to the genius of the model's architect, Gary Russell, and to Andy Lacis' dogged pursuit of precise algorithms to calculate atmospheric radiation. Reto Ruedy, Makiko Sato and I used the model for thousands of climate simulations to help us understand the efficacy of different climate forcing mechanisms.

We used the natural climate experiment provided by the massive Mount Pinatubo volcanic eruption to test understanding of the climate response to a global forcing. We used the model and 20th century greenhouse gas history to infer[5] that Earth was out of energy balance by 0.65 W/m^2, a conclusion, confirmed a decade later, which provided a measure of how difficult it would be to restore Earth's energy balance and stabilize global temperature. Most informative, were studies of climate change based on Earth's paleoclimate record; we were indebted to Jean Jouzel, Valerie Masson-Delmotte and James Zachos for generosity with their extensive data collections and patient sharing of their wisdom about the nature of past climate change.

The period of indulgence in pure science ended in 2004, when I was asked to give a keynote talk at what amounted to a Democratic fundraiser. I declined, since I am a political Independent, but I asked for assistance in finding a venue where I could give a talk criticizing the absence of effective policies to address climate change.

Naively, I imagined I could get public attention, given media coverage of earlier congressional testimony. Evidence for the threat of human-made climate change had improved greatly in the subsequent years, with data including confirmation of Earth's energy imbalance and improved paleoclimate evidence for climate sensitivity. Yet climate policy was clearly fruitless. Greenhouse gas emissions *accelerated* following the 1997 Kyoto Protocol!

My decision to criticize the energy and climate policy of the incumbent federal Administration in an election year was a source of stress. During a presentation to NASA Administrator Sean O'Keefe, he interrupted me, cautioning me not to use the phrase "dangerous anthropogenic interference," because we did not understand climate well enough. I decided that materials for

[5] Hansen, J., M. Sato, R. Ruedy, A. Lacis, et al., 1997: Forcings and chaos in interannual to decadal climate change. *J. Geophys. Res.*, **102**, 25679-25720.

my planned talk would need to be prepared outside my 40-hour government work week. My caution, concern that political extremists would track my every move for the sake of finding ways to discredit my message, would prove to be warranted.

Fortunately, the Rockefeller Family Fund agreed to provide funds to support Makiko Sato, a Columbia University employee, to prepare charts for my presentation. Later, as these funds were running out, I was introduced to philanthropist Gerry Lenfest. Gerry was a craggy, friendly old fellow who listened patiently as I explained why we needed more calculations and more charts. He said that he did not understand what I was saying, but when he was a ne'er-do-well teenager his father made him spend a summer working on an Iowa farm. It straightened him out, and he concluded that Iowans were honest and hardworking. Gerry became my most reliable supporter, whenever I got in trouble – and he never tried to influence what I was communicating.

The period with two simultaneous 40-hour per week jobs was only supposed to last a few months, until the energy/climate talk. When the expected venue for that talk was withdrawn, Prof. James Van Allen kindly arranged for the talk to be given at the University of Iowa. I read the talk, completed at the last minute. As I should have anticipated, it had no significant impact.

However, Ralph Keeling read the talk, and when his father, Charles David Keeling died months later, Ralph asked me to give a talk honoring his father at the 2005 meeting of the American Geophysical Union. This venue had reporters, and I did an interview for ABC television that drew the ire of the White House. Attempted censorship of my public statements by the NASA Office of Public Affairs actually increased attention to the climate change issue.[6]

The period of stress continued and was a blessing. I may have learned more in 2004-2008 than I had in the prior 15 years – about climate science as well as implications for energy policy. Bill McKibben, who was about to form an organization 450.org, asked me to confirm that 450 parts per million (ppm) was an appropriate target for atmospheric CO_2 amount.

This led to collaboration with some of the best relevant scientists in the world.[7] We concluded that the appropriate target was less than 350 ppm. The optimum target is probably not as low as the preindustrial 280 ppm, in part because of other human-made alterations to Earth, but it is unnecessary to define the final target exactly at this time. The "<350 ppm" target already implies that fossil fuel emissions must be phased out as rapidly as practical.

Friction with the highest levels at NASA Headquarters continued. I was warned, when I testified or otherwise spoke in Washington, to talk only about climate science, not policy implications. That admonition fueled my interest in understanding the broader issue of energy policy.

Analysis of the composite energy and climate matter is a scientific problem. The scientific method trains scientists to be objective. Objectivity, not just the opinion of those with special financial interests, is needed in making national and global energy/climate policy decisions.

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[6] Bowen, Mark, 2008: Censoring Science: Inside the Political Attack on Dr. James Hansen and the Truth of Global Warming. New York: Dutton.

[7] Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos, 2008: Target atmospheric CO_2: Where should humanity aim? *Open Atmos. Sci. J.*, **2**, 217-231.

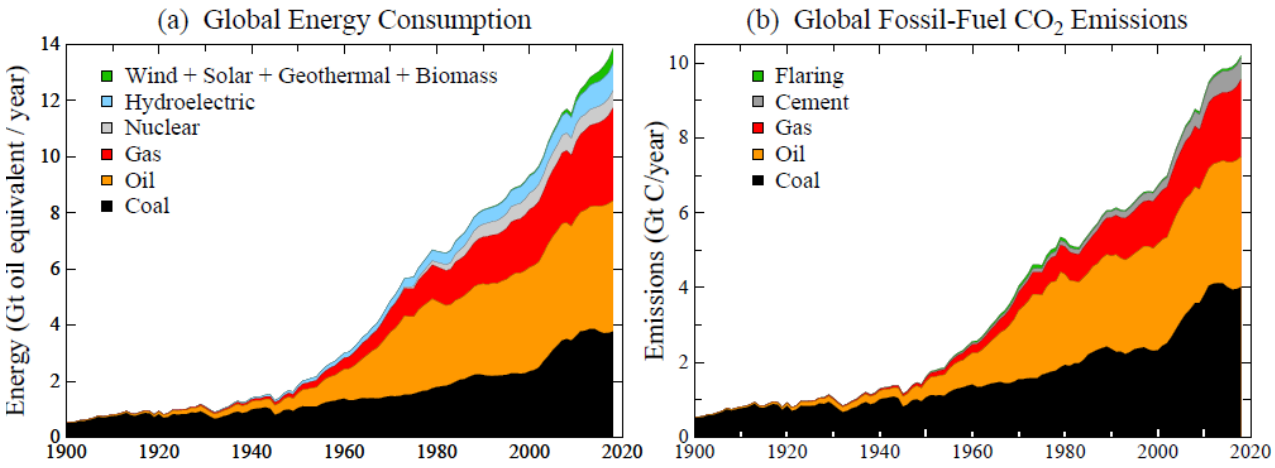

Fig. 1. Global energy consumption and fossil fuel CO_2 emissions.

A strategic vision for stabilizing climate should account for global energy needs and be informed about past, present, and likely future sources of fossil fuel emissions.

Global energy consumption accelerated following the 1997 Kyoto Protocol and continues to rise relentlessly (Fig. 1a), fueled by population growth and the energy needs of nations in which living standards are rising and the portion of population in poverty is declining. Rising living standards are needed as the most effective way to constrain future population, and we must recognize that improved living standards require energy.

Most global energy is provided now by fossil fuels (Fig. 1a), which has caused a persistent rise of fossil fuel CO_2 emissions (Fig. 1b). Coal accounts for almost 30 percent of global energy consumption and more than 40 percent of fossil fuel CO_2 emissions.

Most coal use occurs where massive amounts of energy are needed, especially for industry and production of electricity. Abundant affordable carbon-free electricity is the essential requirement for solving the climate problem, while also addressing pollution problems. Coal is the largest contributor to air pollution. At present outdoor air pollution kills about 10,000 people per day, and indoor pollution, mainly from coal and biofuels, claims a similar number of lives each day.[8] Infants and young people are especially susceptible, accounting for thousands of deaths per day.

Despite the pollution from coal, including CO_2, the desire for energy and higher living standards is so great that coal will continue to be used until adequate alternatives exist. Coal provides most of the energy for China and nations with emerging economies such as India.

[8] World Health Organization, Air Pollution https://www.who.int/airpollution/en/

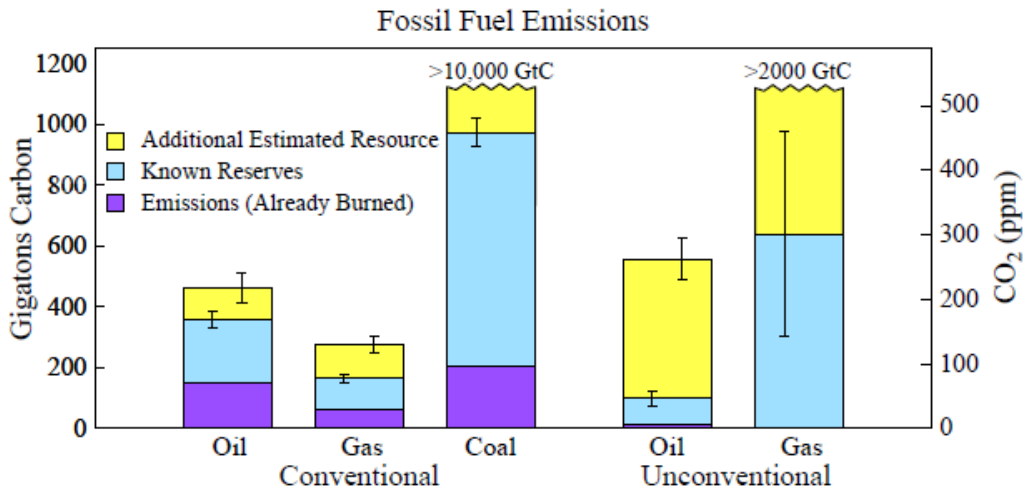

Fig. 2. Fossil fuel CO_2 emissions[9] updated through 2018 and carbon content (1 ppm CO_2 ~ 2.12 GtC, where a gigaton of carbon (GtC) is the same as a petagram of carbon).

Gas, ideally, produces only about 60 percent as much CO_2 as coal per unit energy. However, gas has two problems: (1) there is leakage of methane (a strong greenhouse gas) to the atmosphere, especially if gas is obtained by hydrofracturing, and (2) there is a lot of gas in the ground, especially when the unconventional sources of gas, such as 'fracking,' are included (Fig. 2).

Therefore, replacing coal with gas does little if anything to reduce climate change. Indeed, because the infrastructure for gas, including pipelines and gas-burning facilities, is likely to be long-lived, gas does not provide a climate solution, it is a climate problem. The need is for carbon-free energy such as renewables and nuclear power.

This energy and climate picture was clear already in 2004. Following my 2004/2005 Iowa and AGU talks, I received speaking requests and could accept a few. I included graphs of energy use and CO_2 emissions in these climate talks. One memorable trip was to North Carolina in 2007 for talks in Charlotte and Raleigh-Durham, at the request of Jim Warren, Executive Director of NC WARN (North Carolina Waste Awareness & Reduction Network).

Warren was and is a gentle man and a gentleman, but fierce in his determination to move the Carolinas and the United States to a future of renewable energies and energy efficiency. He asked me to give a talk on the climate impact of fossil fuels and another scientist to give a talk on energy efficiency and renewable energies. Then we had a discussion with the audience.

Warren wanted to pressure Duke Energy to move from fossil fuels to efficiency and renewable energies, so he was delighted to see Jim Rogers, CEO of Duke Energy, in the audience. Before we went on the stage Warren noted that there were likely to be questions about nuclear power. He said that he opposed nuclear power, but I should feel free to give my own opinion.

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[9] Hansen, J., P. Kharecha, M. Sato, V. Masson-Delmotte, F. Ackerman, D. Beerling, P.J. Hearty, O. Hoegh-Guldberg, S.-L. Hsu, C. Parmesan, J. Rockstrom, E.J. Rohling, J. Sachs, P. Smith, K. Steffen, L. Van Susteren, K. von Schuckmann, and J.C. Zachos, 2013: Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature. *PLoS ONE*, **8**, e81648

Amory Lovins

I'm an advisor to major firms and governments in 65+ countries for 40+ years; a practitioner of integrative design for advanced energy efficiency in buildings, vehicles, and industry; a member of the National Petroleum Council 2011–18; author of 31 books and over 600 papers; recipient of the Blue Planet, Volvo, Zayed, Onassis, Nissan, Shingo, and Mitchell Prizes, MacArthur and Ashoka Fellowships, 12 honorary doctorates, the "Alternative Nobel," Heinz, Lindbergh, National Design, and World Technology Awards. In 2009, Time named me one of the world's 100 most influential people, and Foreign Policy, one of the 100 top global thinkers. In 2016, the President of Germany awarded me the Officer's Cross of the Order of Merit.

Fig. 3. From Forbes Magazine Contributor Profile

Indeed, I was asked whether nuclear power should be part of the energy solution. I did not give a direct answer. I said that CO_2 produced by nuclear power, including construction and mining activities, was as low or lower than renewables, but there were issues about nuclear waste, potential for radiation release, and rising construction costs of nuclear power plants. Jim Warren was probably happy with my response.

As I traveled with NC WARN people from one venue to another, and when I was hosted by other environmental groups, I heard comments that put coal and nuclear in the same category, both highly undesirable. Some environmentalists advocated lawsuits against nuclear power plants, with the aim to drag out construction times, to make nuclear power more expensive.

I began to wonder about this opposition to nuclear power. If climate was a great concern did it not make sense for renewables and nuclear power, our largest source of carbon-free energy, to be on the same side, at least until we achieve carbon-free electricity generation? After that, we could let renewables and nuclear power compete.

But perhaps the anti-nukes were right? Why bother with nuclear power, if renewables can provide our energy needs? Amory Lovins argued in the 1970s that there was enormous untapped potential in energy efficiency. Further, he said, with the resulting reduced energy demand, our energy needs could be met with "soft" renewables, with fossil fuels phased out entirely. Soft renewables exclude the large hydroelectric dams that many environmentalists object to.

Amory and I had friendly discussions about this. I argued that a carbon fee was needed to spur efficiency and phaseout of fossil fuels. Also nuclear power likely was needed for baseload electric power – otherwise gas would be used when intermittent renewables were not available.

Amory defended his position, arguing that efficiency was not yet being exploited. Business and industry, in effect, were leaving hundred-dollar bills on the ground, he said, not bothering to pick up the benefits of better energy efficiency. He said that a carbon tax was not needed, nor were oil, gas or coal. Nuclear power was not needed, nor was large hydro.

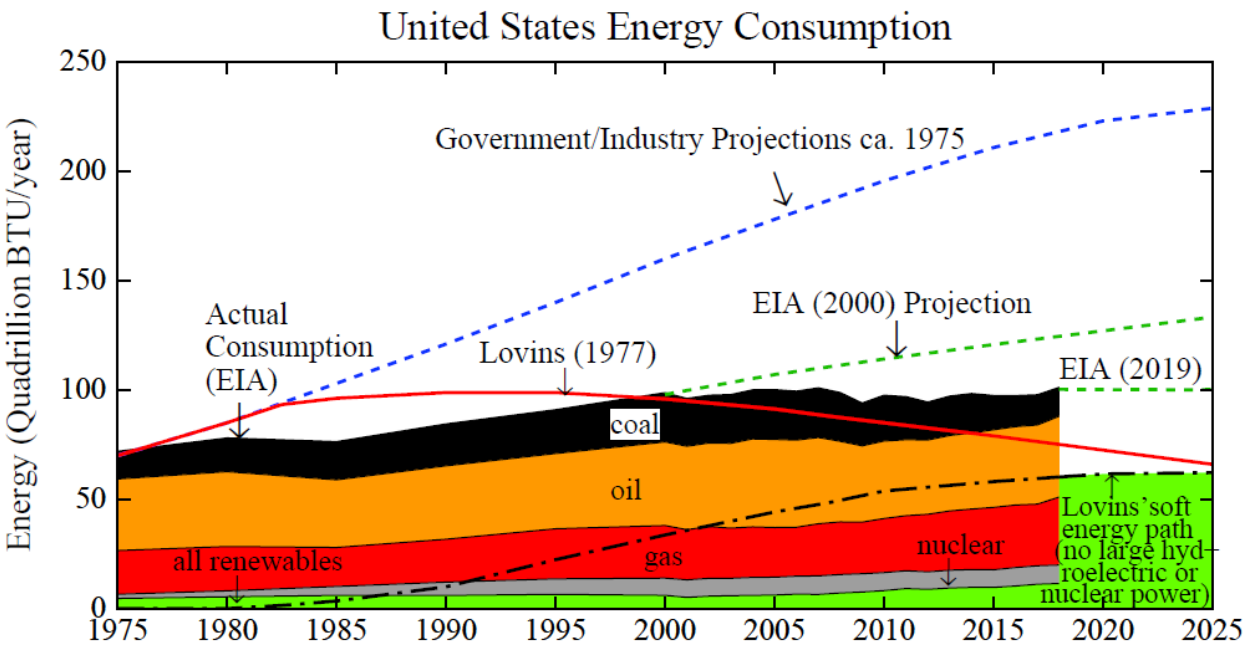

Fig. 4. U.S. energy consumption (upper edge of black area), Lovins' projection for U.S. energy consumption (red line), and his projection for soft renewables (dash-dot line).

All of these things "not needed" are banes of environmentalists and of liberal politicians who want the support of environmentalists. It is no wonder that Amory was and is popular!

Anniek and I spoke with Amory at the Tallberg Forum in Sweden. He is a persuasive salesman for renewables, but he was also anti-nuclear, as he seemed to believe that renewables and nuclear power are in competition. When I questioned whether his conclusion that renewables plus efficiency are sufficient for our energy needs, he buried us in a boatload of numbers to bolster his case. He has a great depth of knowledge about energy, especially energy efficiency.

Amory Lovins advises governments worldwide (Fig. 3) and is the most effective energy adviser in the world. Indeed, Amory was energy adviser to Bill Clinton, when Clinton was Governor of Arkansas. After Clinton was elected President, in his first State of the Union address in early 1993, he announced "We are eliminating programs that are no longer needed, such as nuclear power research and development." This was consistent with Lovins' opinion.

Yet we must continually assess conclusions by comparison with real world data. I had a copy of Lovins' projections for U.S. energy consumption made in the mid-1970s, which I could compare with reality (Fig. 4)[10]. Lovins was partly right: government projections overstated growth of energy consumption. Actual energy use increased 'only' from 70 to 100 Quadrillion BTU's.

However, the goal of phasing out fossil fuels by 2015 is not being met. If we expand the vertical scale, we find that renewable energy actually increased sharply in recent years (Fig. 5, left) and it is now a substantial contributor to the five-fold growth or carbon-free energy since 1970 (Fig. 5 middle). However, about 80 percent of our energy is still supplied by fossil fuels.

[10] Update of figure in Hansen, J., 2009: Storms of My Grandchildren, Bloomsbury, New York, 320 pages.

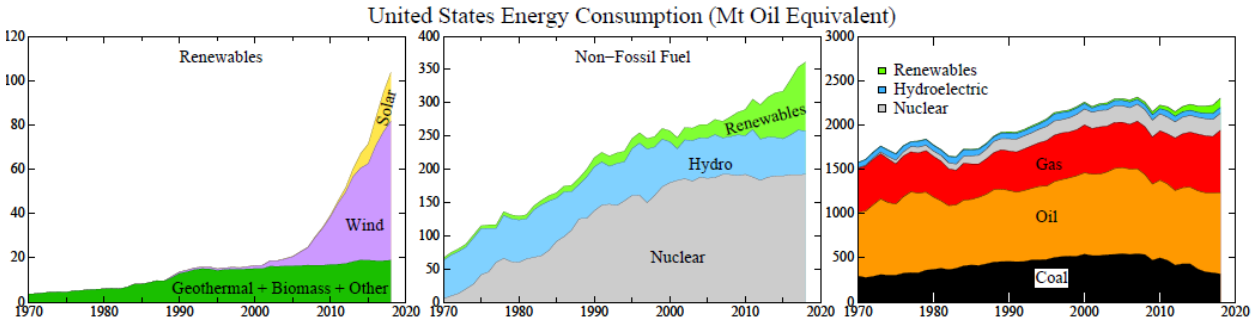

Fig. 5. United States energy consumption and fossil fuel CO_2 emissions.

Why have we been slow to phase down emissions, despite realization of likely consequences? Why did we fall short, despite trying hard? Let's first look at things that we did right.

Politicians and leading environmental organizations strongly supported Lovins' vision. National and many state governments granted explicit subsidies to renewable energy. More important, most states enacted renewable portfolio standards (RPSs) that required utilities to use renewable energy for a growing fraction of their power.

The RPS subsidy is huge but usually not calculated, because it is not paid directly by taxes. Households that do not have solar panels, or choose another renewable energy source for their electricity, bear part of the cost, as the utility raises the electric rate to maintain profitability.

The RPSs worked for my family. We covered our large barn roof and a smaller roof with solar panels. Pennsylvania gave us $17,000, the federal government an additional $23,000, and the utility was forced to buy the excess electricity we generated, whether they wanted it or not. Besides these subsidies by taxpayers, other utility customers footed part of the bill via increased electricity rates. The public will accept these burdens, if they remain small enough.

These subsidies worked for the primary intended purpose: to drive down the unit price of renewable energies. As the market for renewable energies grew, the price fell via technical innovations spurred by competition (Fig. 6). China played a major role in driving down unit costs. Via government support and marketing opportunities, China became the major supplier of renewable energies to the international market and to slake its own desire for clean energy.

Rapid replacement of old technology imposes costs. Strong government support was needed to drive down renewable costs rapidly. In contrast, cost of nuclear power rose, as government support of nuclear RD&D dropped, nuclear power was excluded from RPSs and excluded as a Clean Development Mechanism in the Kyoto Protocol, and nuclear power was successfully targeted by the Big Green environmental groups that emerged in the 'boomer' generation.

Despite the success in driving down renewable costs, cheap renewables and energy efficiency are not causing phaseout or even phasedown of global fossil fuel emissions (Fig. 1), certainly not the rapid phasedown that is needed. Why was the Lovins strategy falling short?

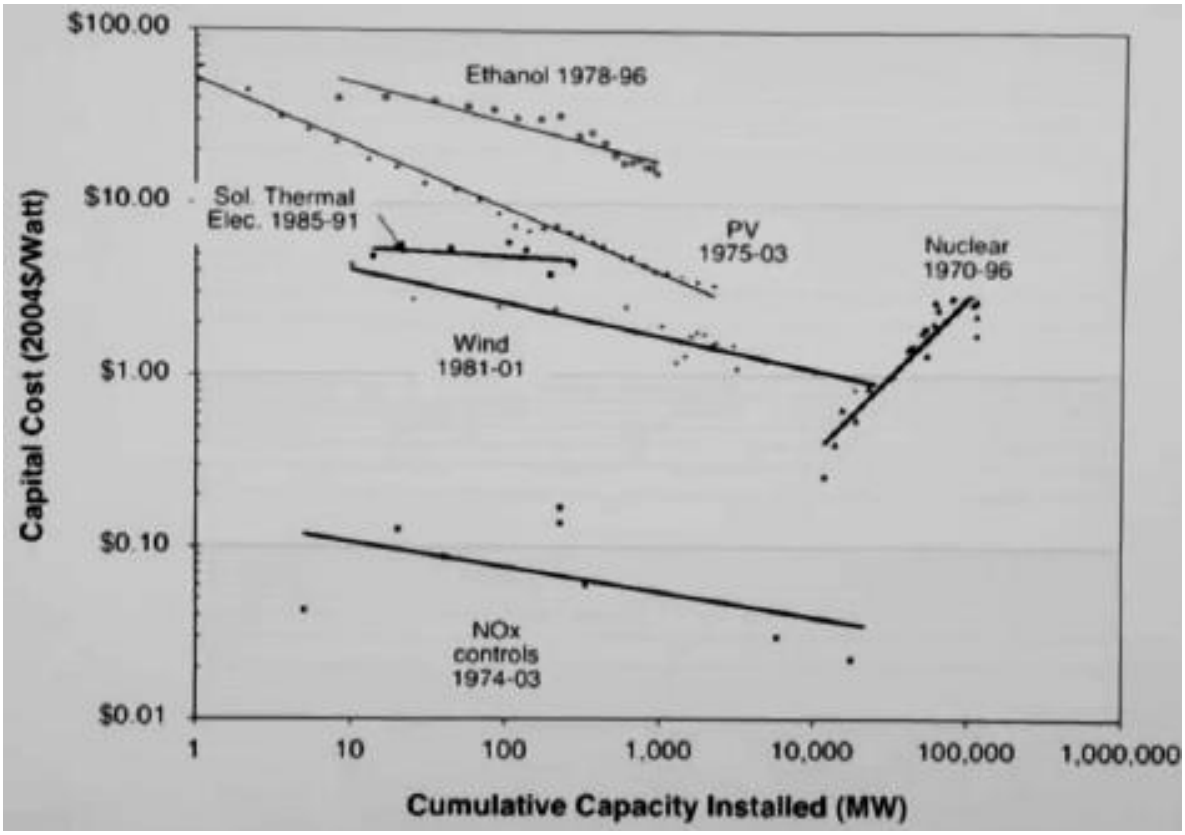

Fig. 6. Capital cost of installed energy sources versus cumulative installed capacity.

The answer became clear at a meeting of oil industry executives in London, where I gave a talk on global climate change. I had the opportunity to speak with some participants at the morning coffee break. These were not CEOs, but rather middle level management people.

I asked about the windmills on their web page: were they seriously getting into the renewable energy business, or were these for show, what David Cone (Yankee baseball announcer) calls eye wash? They just smirked, which confirmed the latter interpretation.

Then I asked my main question. Was their industry concerned about the Lovins strategy, which seemed to have been adopted by some governments, such as the Clinton/Gore administration? Lovins' strategy would have the fossil fuel industry getting phased out of business.

They laughed. Efficiency was fine, they said, but improved efficiency would not reduce global fossil fuel use. It is no wonder that oil industry executives are on the board of the Rocky Mountain Institute and write glowing introductions for Lovins' book.[11] Their industry is not threatened by his policy prescription.

They were right. Fossil fuels are a convenient, condensed energy source. An enormous amount is easily available (Fig. 2). As long as fossil fuels are not required to pay their costs to society, they will continue to be burned. The costs, from air pollution, water pollution and climate change, are huge.

[11] Lovins, A.B., 2011: Reinventing Fire, Chelsea Green, ISBN 978-1-60358-371-8

The clear answer was: the way to phase out fossil fuels is to collect a gradually rising across-the-board (oil, gas, coal) carbon fee, which is collected at the first sale at domestic mines and ports of entry. If the fee is added gradually, it has no cost – in fact it has negative cost, as economists agree: an economy is more efficient, generating more wealth, when prices are honest.

The carbon price must rise steadily, so that fossil fuel emissions are phased out on the long run. The public in the U.S.[12] will not tolerate rising fuel prices, if the government grabs the money. However, if the fee collected from the fossil fuel companies is distributed uniformly to legal residents, 70% of the public comes out ahead. Fee & dividend is progressive, as wealthy people have a large carbon footprint and will lose money, but they can afford it.

Communication of "fee & dividend" with the public is not easy. A common response is: "if you give the money to the public, they will use it to maintain fossil fuel guzzling." The public is really that stupid? When the price of a product made with fossil fuels rises far above a similar product made without fossil fuels, the public will buy the expensive one? Economists disagree with that; their studies show that a rising carbon fee is the fastest way to phase out fossil fuels.

Communication with politicians is even harder. In 2008 and later years I included fee & dividend in my presentations,[13] and it was the policy that I advocated when I had the opportunity to speak with politicians in several nations. They would listen, but, in every case, even when they agreed about the climate science, they stuck with "cap & trade" as their preferred policy.

In frustration with my inability to be persuasive, I once called California's climate policy "half baked," and worse, with California Governor Jerry Brown in the audience front row. Governor Brown laughed and said that his policy was "pretty darned good."

Whence came cap & trade? The U.S. advocated that approach for the Kyoto Protocol in 1997. Cap & trade had been used successfully to achieve a 50% reduction of sulfur emissions from coal-burning utilities, allowing the costs of fixing the dirtiest plants to be shared. Politicians also wanted to avoid the word "tax." The public is not so stupid, however. As soon as the Australian government adopted cap & trade for CO_2 emissions, they were rightfully thrown out of office.

Peter Barnes argues for a "cap and dividend" policy.[14] Funds collected in auctions of the right to burn fossil fuels in various activities would be distributed as a dividend to the public. A dividend might have avoided the negative public reaction in Australia, but how can one "cap" the totality of carbon (CO_2) emissions? The practical way is a carbon fee at the source.

Unfortunately, the "cap and trade" idea caught on with politicians, bankers, and tricksters in general. Big banks such as Goldman Sachs and J.P. Morgan like it, because they have skilled trading units that can make billions, every cent coming out of the public's hide. Politicians can use the money from auctions of "the right to pollute" for their favorite projects – Governor Brown wanted to build a railroad between San Francisco and Los Angeles.

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[12] Nor in France: cf. 'yellow vests.' Nor in Australia: the public dismissed a government for imposing cap & trade.

[13] Hansen, J.: Climate threat to the planet: implications for energy policy, PACON International, Hawaii, 3 June 2008.

[14] Barnes, P., 2014: *With Liberty and Dividends for All,* Berrett-Koehler Publishers, San Francisco, 193 pages.

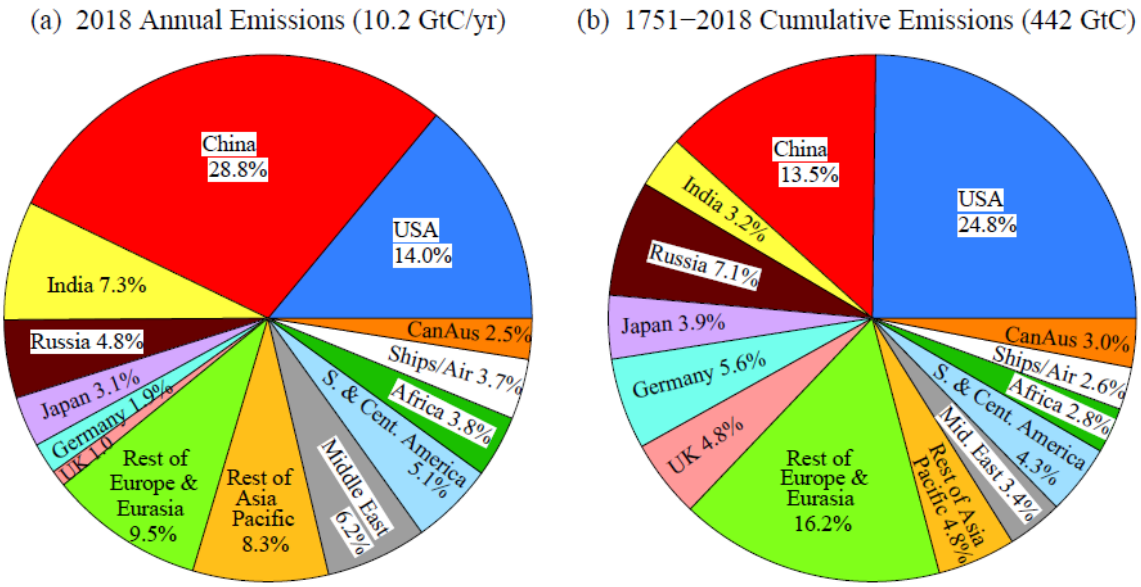

Fig. 7. Current and cumulative fossil fuel CO_2 emissions (update of published[15] figure).

How could a "cap" approach work for global emissions? What is the cap on India? What is the cap on Indonesia? What is the cap on Vietnam? You get the idea. The Paris Agreement begs each of 200 nations to please lower their cap, whatever it is. Diplomats utter sweet nothings, but, in reality, most nations will do what they deem to be in their best interest.

A carbon fee, in contrast, can be made global or near global more readily. If the United States or China, or preferably both, decided to have a substantial carbon fee, they would place a border duty on products from countries that did not have an equivalent fee, and they would rebate the fee to domestic manufacturers on goods shipped to a country without a carbon fee. That would be an incentive for other countries to have their own carbon fee, so they could collect the money.

Imposition of a global carbon fee should be done with recognition of the fact that some countries have contributed little to the global climate problem and deserve a chance to raise their standard of living. That fact implies a need for assistance and technology transfer. It is in the interest of all countries that progress continue in eliminating global poverty.

China is the largest source of fossil fuel emissions today (Fig. 7a), but the United States is most responsible for excess CO_2 in the air today (Fig. 7b). Global climate change is proportional to cumulative emissions.[16,17] Per capita, the United States, Australia, Canada, the Middle East and Russia are high emitters today (Fig. 8a), but cumulative per capita (using current population) emissions are greatest from the United States, the United Kingdom and Germany (Fig. 8b).

[15] Hansen, J. and M. Sato, 2016: Regional Climate Change and National Responsibilities *Envir. Res. Lett.* **11** 034009.
[16] Hansen, J., M. Sato, R. Ruedy, P. Kharecha, A. Lacis, R.L. Miller, L. Nazarenko, K. Lo, G.A. Schmidt, G. Russell et al., 2007: Dangerous human-made interference with climate: A GISS modelE study. *Atmos. Chem. Phys.*, **7**, 2287-2312.
[17] Matthews, H.D. *et al.*, 2009: The proportionality of global warming to cumulative emissions, *Nature*, 495, 829-32.

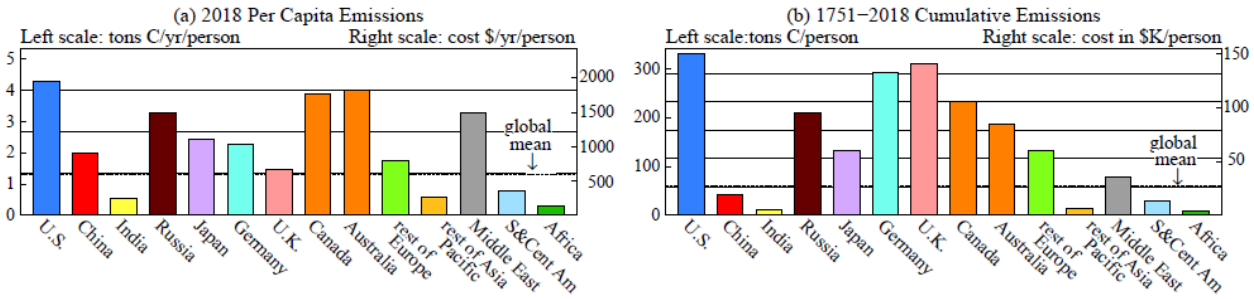

Fig. 8. Per capita fossil fuel CO_2 emissions in 2018 and cumulative (updated figure[10]).

Think global, act local. National energy strategies must be chosen with an awareness of the global energy and climate situation. I already implied two examples of 'think global.'

First, a carbon fee or tax is more appropriate than a cap approach. The sum of acceptable caps is not as small as needed. The fee is a single number defined by participating nations (e.g., the United States and China) and imposed near globally by border duties on products from non-participating nations, which is a big incentive for other nations to participate, so they can collect the money themselves. A rising fee is also the fastest way to phase off fossil fuels.

Second, there is a large range in national responsibilities for climate change (Figs. 7b and 8b). This must be addressed, and can be via mutually beneficial policies, as discussed below.

A third, overriding, reason to think global: as Carl Sagan said, we all live on the "pale blue dot," our small, remarkably complex world, observed by the Voyager 1 spacecraft as it left our Solar System and looked back at Earth.[18] We enjoy our planet's wonders together, and we will experience our planet's fate together.

This third reason to cooperate with urgency, so far, has had little impact. That situation will change soon, as the threat of large sea level rise comes into clearer view. The emerging danger of losing more than half of the world's large cities, along with continued warming that could make the tropics and subtropics almost unlivable, threatens to create an emigration crisis that would make the planet ungovernable.

Fortunately, the actions that are needed to avert such catastrophe make good economic and common sense. Unfortunately, these actions are not being proposed by existing politicians.

To clarify these assertions, I must summarize a few more elements in my own education. Let's first complete the story about the notorious Jim Rogers and the notorious Jim Warren.

Jim Warren wanted me to pressure Duke Energy to go all in on all-renewables and close nuclear, coal, and gas power plants. It was not clear that Warren had a realistic understanding of the magnitude of global electricity needs. On the other hand, Rogers was planning to replace a

[18] "Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate….it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known." – Carl Sagan, Pale Blue Dot: A Vision of Human Future in Space.

dirty, inefficient coal-fired power plant with a new more energy efficient coal-fired power plant. So it was not clear that Rogers understood the urgency of the climate matter.

I took an intermediate path: I wrote an open letter to Rogers, releasing it to the public in one of my Communications (Mr. Rogers and Darth Vader). I criticized Rogers' proposed coal plant, but noted the crucial role that could be played by our "captains of industry." I proposed that we have a one-day workshop with some of the top experts in energy efficiency, renewable energy, carbon capture, and nuclear power. As a respected captain of industry, Rogers could help inspire and inform the public and persuade politicians about actions needed to stabilize climate.

Somewhat to my surprise, Mr. Rogers was interested! Afterall, I was just a scientist, he was CEO of a huge organization – according to Warren, Rogers' compensation that year was $28M. Mr. Rogers suggested that we talk about the workshop idea on one of his next trips to New York.

In the meantime, I was contacted by Eric Svenson, a Vice President of PSE&G, a huge utility in the Northeast United States, comparable in size to Duke Energy. Ralph Izzo, Chairman and CEO of PSE&G, wanted me to give a climate talk to him and the top 12 PSE&G executives.

On 11 April 2008 I took a local train to Princeton Junction, New Jersey. There waiting was a long, shiny white limousine, longer than any I had seen. It could have carried a baseball team. I sat about halfway back, in case I needed to talk to the driver.

Ralph Izzo did not need to be persuaded about climate change. He was trained as a physicist, and under his leadership PSE&G had advocated for cap-and-trade national legislation with aggressive greenhouse gas emission reduction targets.

My presentation focused on climate, with a few charts about policy, as in the presentation Climate Threat to the Planet: Implications for Energy Policy, which is on my website.

My main policy pitch was for what I called "carbon tax & 100% dividend." In 2009 I changed the name to "carbon fee & dividend" to emphasize that no money goes to the government.

My secondary pitch was for a "national high-voltage low-loss DC grid." The idea was that a low-loss national grid would allow intermittent renewables to be connected with dispatchable electricity of hydro and nuclear power plants.

Discussion at PSE&G was friendly. In retrospect, I should have spent less time on climate science, and more on the policy implications. Izzo proposed that PSE&G would be glad to host the workshop that I had proposed to Mr. Rogers. Perhaps that was one reason that I had been invited to speak. PSE&G wanted to have their oar in the water, to help steer the policy boat, because their views did not coincide with those of Duke Energy.

Izzo and Rogers were both imagining a cap & trade system: utilities would be allocated emission allowances or purchase them at an auction. Eric Svenson summarized for me his understanding of the differences between the PSE&G and Duke cap & trade preferences. The complications of cap & trade only reinforced my opinion that a carbon fee is much better and more effective.

The cap & trade system is political and prone to graft as companies seek allowances. A large government bureaucracy is spawned if all uses of fossil fuels are to be capped, not just utilities. A carbon fee is simple and comprehensive. The fee, a single number, dollars per ton of carbon, is collected where fossil fuels first enter the economy, at the domestic mine or port-of-entry.

Cap & trade is designed to hide the fact that the public will have to pay more for energy. The public gets nothing in return. I call it cap & tax, because that is a more accurate description.

The perspectives of the utility CEOs differed from my perspective, as a global climate modeler. The merit of single number simplicity, an across-the-board fee, i.e., on all fossil fuels – oil, gas and coal – makes it easier to achieve global equivalence in carbon price.

Dinner with Mr. Rogers was 19 May 2008 at Nello Restaurant on Madison Avenue. We had a friendly three-hour discussion. We decided that the workshop should be held in Washington, so that Congress people and/or their staffers could attend. That suggestion actually came from Senator Carper, who I had met recently at a dinner in Delaware.

Senator Carper suggested Waxman, Warner, Bingaman and Domenici as participants, but Rogers noted that Domenici was retiring, and we soon realized that Warner was also retiring. We agreed to aim for comparable representation from both political parties.

A good-old-boy Southern businessman, acquainted with Rogers, stopping by our table briefly. He ranted about global warming nonsense. Neither Rogers nor I made any effort to educate him. That incident may explain a difference between Izzo and Rogers. Izzo, functioning in the liberal Northeast, seemed more concerned with climate, the need to slow carbon emissions rapidly.

However, both Izzo and Rogers made no bones about the fact that their first obligation was to make a profit for shareholders. They both said they could phase out carbon emissions and make a profit, but the time needed for phaseout depended on the government providing guidance: a plan for tightening the carbon cap over time, or a schedule for a rising carbon fee.

Workshop planning suffered as I was running around the world in 2008, as is apparent from my 2008 Communications (http://www.columbia.edu/~jeh1/mailings/), trying to draw attention to the universal "greenwashing" of the climate problem by all nations, including those that claimed to be doing the most. Global emissions surely would continue to rise as long as fossil fuels were allowed to be cheap. There was no effective global or national plan to deal with the matter.

The trips were frustrating. Curiously, it was easier to get appointments with high government officials in other nations than in the United States. Also easier to get media attention. However, all the running around bore no significant fruit. The one 'success,' helping to get the Kingsnorth Six declared innocent after they shut down the biggest coal fired powerplant in the UK, amounted to little, as the UK government did not change its energy policies.

It was no better on the home front. Izzo and Rogers ganged up on us. They insisted that the workshop should be after the election, so they would know who they were dealing with in the White House. My preference was a discussion and energy planning independent of politics.

Maybe they were right. Something useful might have been accomplished, if we had done it their way. They were big enough that they would have been listened to by politicians, especially if they could say that they had produced recommendations with a group of scientists.

Instead, I went ahead with a mini-workshop prior to the 2008 Presidential election. I said we can have another meeting later, but first we should educate ourselves outside politics. We held the workshop in Washington the week before the election. The CEOs, of course, did not attend, but some congressional staffers did. We produced a report that was eventually published.[19]

Obama was elected the next week. He had talked about a planet in peril during the campaign. And he promised to slow the rising seas. That's a pretty tall order. It's possible, but if he were serious, it implied urgent priority to climate on both national and international stages.

How much did he really understand? Did he understand the urgency of actions? Did he have a good concept for policies that needed to be enacted? I wanted to offer advice, but the problem was that a million people wanted to offer advice to the new Administration.

We were in a good position to provide advice – just a few days before the election our paper Target Atmospheric CO_2: Where Should Humanity Aim? was published. So I wrote a Communication for my website, Tell Barack Obama the Truth — the Whole Truth, hoping that people with access to Obama would read it.

I was in London, again. My trips began at the behest of a persuasive Brit, George Polk, who was determined to "shift the excellent rhetoric that we have in the U.K. [about climate] into action." At least he was able to secure meetings with high level officials. On this trip, Anniek was with me. I did not notice, as we ran from one meeting to another, that she was falling behind and holding her scarf over her mouth. I should have paid attention. She had a heart attack.

Fortunately, it was not too serious, but it required a stent, so we could not fly for several days. While we were waiting, we wrote a letter to Barack and Michelle Obama. But what to do with it?

Putting it in the U.S. mail was like sending it to a Black Hole. Ah, I saw a chance. Obama chose John Holdren to be his Science Adviser. Holdren was friendly and in the past had asked for my powerpoint charts on climate science. I sent the letter to Holdren and asked him to communicate it to Obama. Holdren declined, saying that he had not yet been confirmed by the Senate.

I decided to put the letter (Dear Michelle and Barack) on my website, not expecting Obama to read it, but hoping that one of his advisers may consider my rationale. The letter to Obama was long, four pages, but my cover note to Holdren served as an executive summary.

The letter and note included three topics: (1) coal, (2) carbon fee & dividend, (3) nuclear power. These three topics led to two policy implications: (1) fee & dividend instead of cap & trade, (2) high priority RD&D[20] for advanced generation nuclear power.

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[19] Kharecha, P.A., C.F. Kutscher, J.E. Hansen, and E. Mazria, 2010: Options for near-term phaseout of CO_2 emissions from coal use in the United States. *Environ. Sci. Technol.*, **44**, 4050-4062

[20] Research, development and demonstration.

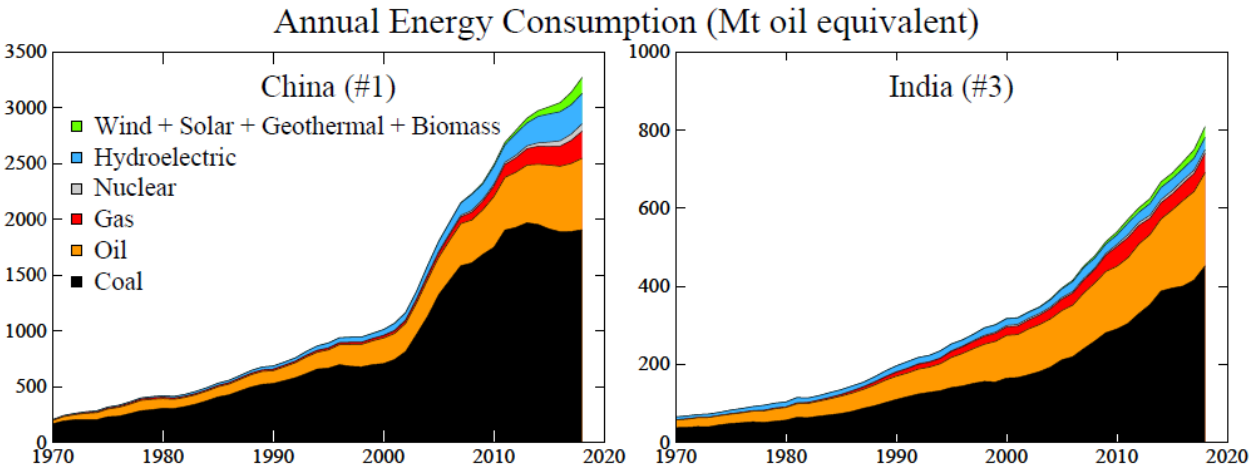

Fig. 9. Energy consumption by China and India.

Coal phase-out would be achieved by (2) and (3). The debate about whether nuclear power was desirable in the long-term plans for the U.S. could be deferred. However, advanced generation nuclear power was surely needed for China and India to avoid global catastrophic 21st century CO_2 emissions and for the sake of human health in those countries. Coal is even more dominant in the CO_2 emissions of those countries than it is in their energy production (Fig. 9). The U.S. has a moral obligation, and a strong self-interest, to cooperate in their clean energy development, given the fact that we burned far more than our share of the allowable global carbon budget.

Al Gore called. He was about to meet with Obama, to suggest infrastructure investments. Obama would be able to get a bill through Congress, because of the economic crisis. However, he doubtless would be getting suggestions from many people.

I had two infrastructure suggestions: (1) initiate construction of a national smart electric grid with a low-loss (high voltage) backbone to allow maximum exploitation of renewable energies, and (2) ask the Department of Energy to build a single 4th generation nuclear power plant as a demonstration and test of capability.

The nuclear power suggestion required first persuading Gore. I asked him to have a one-day meeting with nuclear engineering experts, who could explain the merits of improved, so-called 4th generation technology, including (1) inherent safety characteristics over the existing fleet, already our safest[21] form of electricity, (2) ability to 'burn' much more of the nuclear fuel; present reactors utilize only 0.6% of the fuel; thus the volume of waste could be reduced.

Gore agreed to the nuclear meeting. That was exciting. Even if the U.S. did not deploy the next generation of reactors, solving the climate issue hinged on getting China and India off coal. Next generation nuclear power was almost certainly required for that purpose.

I also mentioned carbon fee and dividend, as the essential underlying policy. Gore called again just before speaking to a joint Senate-House meeting. He promised to advocate a carbon fee.

[21] Even solar panels cause more deaths, as installers sometimes fall off roofs or electrocute themselves.

None of these suggestions bore fruit during the Obama Administration. Failure to invest in a modern electrical grid is hard to understand. Everyone should be supportive of a more secure, efficient grid. It is needed so that we can take best advantage of renewable energies.

The meeting of nuclear experts occurred. I could not attend, as I had NASA work; energy studies were extra curricula. A participant reported excitedly to me that even Amory Lovins, who was also a participant, could hardly object to the proposal to build a single trial reactor, and the advocates for building had good technical answers for every criticism by Lovins.

When I learned that Gore opened the meeting with profuse extended praise of Lovins, and that a dedicated nuclear power critic was invited to give the final talk of the day, I was almost certain that nothing would come of the meeting. I was right. When Gore's next book came out, the section on nuclear power looked as though it could have been written by Amory Lovins.

I was frustrated by the god-like reverence to Lovins. It reminded me of Anniek's description of Lovins as a salesman and a question she asked. Although Lovins is a top-100 thinker according to Time and Foreign Policy magazines, she noted that it is easy to get those designations by being in the news. If he was so brilliant, why was he not in the National Academy of Sciences?

That matter is not so simple. Election to the Academy is a fraught process. I argue in *Sophie's Planet* that Carl Sagan deserved to be in the Academy, but other factors can intervene.

I listened to Gore's address to the joint Senate-House meeting with anticipation, but he only briefly mentioned the need for a carbon price. There was no discussion of the fundamental differences among alternative methods to price carbon.

President Obama recognized the need for a carbon price, but had other priorities. John Kerry was given the task of pushing a cap & trade bill through Congress. The Democrats had a majority in both House and Senate. However, Kerry's plan had little chance, because of instant opposition (appropriate, in my opinion) by fiscal conservatives and the fossil fuel industry.

Kerry was kind enough to give me a long audience in his office, but I failed to persuade him that fee & dividend (I was still calling it carbon tax and 100% dividend) was better than cap & trade. His reason: "I can't get one vote for that." Instead, he pushed a bill (Waxman/Markey) that had 1400 pages of giveaways to almost every lobbyist who could raise him arm to write.[22]

I testified for fee & dividend to the House Ways & Means Committee. Fee & dividend puts money in the hands of low and middle income people, which would spur the economy and help alleviate the financial crisis and recession. If Obama had pushed this as part of the financial recovery, it would have had an excellent chance, as it is a conservative cost-free stimulus. Obama lost an opportunity, perhaps because his advisers were big banks and Wall Street.

[22] Hansen, J., 2009: Storms of My Grandchildren, Bloomsbury, New York, 320 pages.

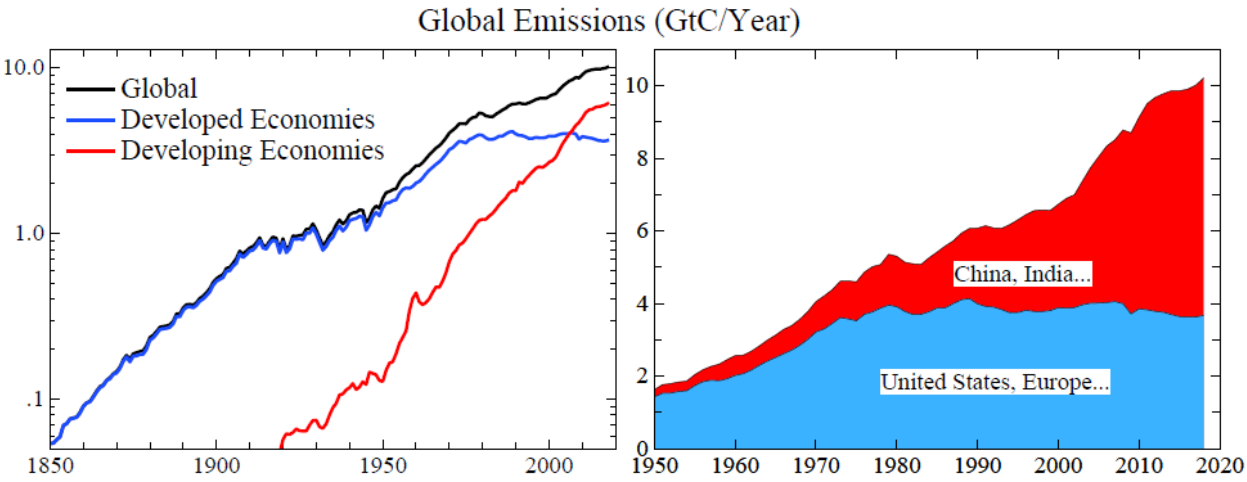

Fig. 10. Fossil fuel emissions; data in right graph is the same as on left, but vertical scale is linear.

It was quickly apparent that Obama did not 'get it.' He was not even attempting to take the actions needed to deal with climate. Was that his fault, or had we, the scientific community failed to define the magnitude and nature of the task?

Was Obama necessarily living in two worlds, the environmentalists' world and the realists' world? Let's examine data before we answer that question.

The situation was clear, based on experience after the 1997 Kyoto Protocol. High emissions of CO_2 not only continued following the Protocol, they increased (Fig. 10). The right half of Fig. 10 is especially illuminating, as it illustrates the reasons for my recommendations to Obama.

Developed country emissions have barely declined, and would show no decline if it were not for the fact that many of our products are now produced in developing countries. Regulations and "caps' have little net effect, if there is no across-the-board carbon fee. Reduced demand due to regulations and efficiency keeps the fossil fuel price low, so it is used other places for other purposes. In contrast, a rising carbon fee at the fossil fuel source (mine or port of entry) can reduce emissions more than 50 percent in 20 years.

The red portion of Fig. 10 is even more important. Developing economies, such as India's, still have a long way to go. They need abundant, affordable energy to raise living standards. They prefer clean carbon-free energy, but they will use fossil fuels if there is no viable alternative.

The West cannot ignore the rising emissions in developing countries or pretend that the Paris agreement will stop that rise. We, the West, burned more than our share of the global carbon budget. Even if we choose to ignore our moral obligation, we cannot ignore the fact that we all suffer the consequences, if we do not phase out global emissions over the next several decades.

Something didn't add up. Utility executives that I met guffawed at the notion of total reliance on Lovins' 'soft' renewables. They said that if nuclear power were excluded, gas would be the primary source of dispatchable electric power used to supplement renewables. The enormous amount of gas in the ground (Fig. 2) is enough to cause cataclysmic climate change.

Something irrational was going on. But there had to be a rational explanation for why people were behaving irrationally. Oh, my. This probably was going to be a complicated story.

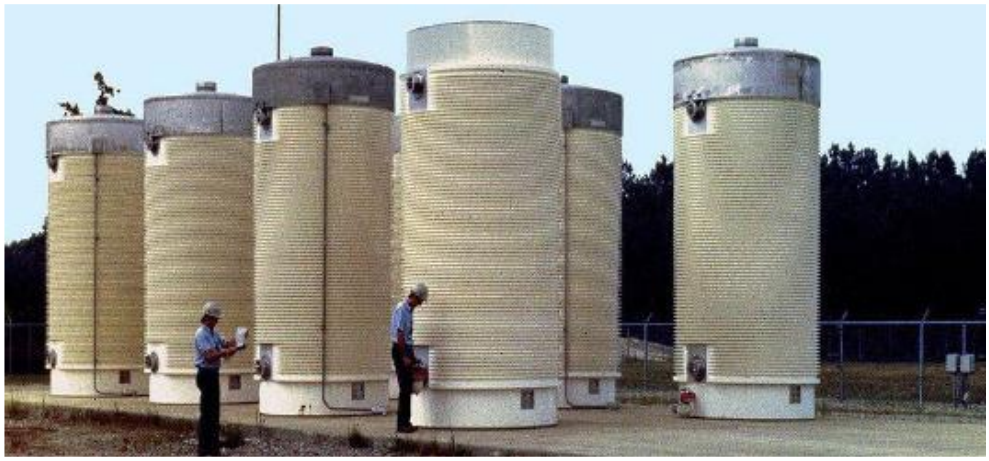

Fig. 11. Nuclear waste from a power plant, stored in dry cask containers.

Nuclear waste was the first irrationality that caught my attention. Nuclear waste at present is stored at the power plants (Fig. 11). It does not harm anybody.

In contrast, waste from fossil fuel burning is dumped into the atmosphere and spread globally by the winds. It kills thousands of people ***per day***. That's the tip of the iceberg. The health of millions of people is harmed by fossil fuel waste,[23] at an annual cost of trillions of dollars.

All energies, even solar panels, produce waste. Many solar panels enter the electronic waste stream, often taken apart in poor communities. Harmful components – heavy metals such as cadmium, chromium, lead – are stable elements. Unlike nuclear waste, their toxicity does not decay over time.

This is not to say that we should oppose solar power. Solar waste and nuclear waste are trivial in comparison with fossil fuel waste. Fossil fuel waste travels thousands of miles and is drifting down from the atmosphere over our entire planetary surface. A significant fraction of air pollution in the United States comes from the Far East.

Fossil fuel waste is a large fraction of the human-made chemical soup that we are living in, polluting the food that we eat as well as the air we breathe. Rational analysis says that we should all be on the side of renewable energies and nuclear power, until fossil fuels are eliminated.

As one small contribution toward encouraging rationality, we decided to calculate, very conservatively, how many lives were saved by the replacement of fossil fuels by nuclear power. It is in the millions,[24] and it will grow enormously as India and China build nuclear power.

The U.S. planned to store nuclear waste in a geologically stable underground site. Geologists agreed that was safe, but politics intervened. 'Politics' was a clue, but not a complete answer.

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[23] Cohen, A., et al., 2017: Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015, *The Lancet*, **389**, 1907-1918.

[24] Kharecha, P.A., and J.E. Hansen, 2013a: Prevented mortality and greenhouse gas emissions from historical and projected nuclear power. *Environ. Sci. Technol.*, **47**, 4889-4895

I found a wise man. In *Storms of My Grandchildren* I included commentary about the potential benefits of nuclear power for stabilizing global climate, but my understanding of nuclear power was superficial. My graduate training in physics included courses in nuclear physics, but what is needed is practical training in nuclear engineering. Fortunately, not long after finishing my book, I met George Stanford of Yale University.

George was retired from the government. He had spent most of his career as a nuclear reactor physicist at Argonne National Laboratory in experimental work on power-reactor safety. I was directed to him because my first interest in nuclear power[25] was the concept of a 'fast' reactor that could utilize a larger fraction of the nuclear fuel, and George was a member of the Argonne team that developed a prototype fast[26] reactor.

George was patient in answering my questions. He explained the physics and was quantitative in his expertise. His calm, careful demeanor reminded me of Van Allen. So I also asked him about 'nuclear fear.' He said that it was partly because the public associated nuclear war with nuclear power. Too late it was realized that the terminology should have been fission energy and fission power plants, thus avoiding association of peaceful use of nuclear energy with nuclear war.

Public fear of even the tiniest level of nuclear radiation was the main issue, however. Whence came that fear? George sighed, and then mentioned two sources. One was research of Hermann Muller in the 1930s that found mutations in fruit flies exposed to high levels of radiation. When Muller received a Nobel Prize in 1946, he asserted that radiation damage was linearly proportional to radiation amount, so even the smallest level of radiation would cause a small amount of harm. However, he did not present data for low levels of radiation.

A second source of fear of low-level radiation was the public campaign by Linus Pauling[27] against atmospheric testing of nuclear weapons. Atmospheric testing over the Pacific Ocean by the U.S. and the USSR. was causing nuclear radiation fallout all around the world, and Pauling asserted that any level of such radiation was harmful to human health. This campaign may have helped achieve the limited Nuclear Test Ban Treaty, which caused the U.S., USSR and the UK to move their nuclear weapons testing underground, to avoid radiation release.

Concerns about radiation were then heightened by accidents at nuclear power plants –Three Mile Island in Pennsylvania in 1979, Chernobyl in the USSR in 1986, and Fukushima in Japan in 2011 – that released radiation to the environment.

Nuclear power advocates point out that deaths from nuclear accidents in all history are less than the number of people who die in one day from fossil fuel emissions. However, both Chernobyl

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[25] Blees, T., 2008: Prescription for the Planet, 429 pp., ISBN: 1-4196-5582-5, available at http://www.thesciencecouncil.com/pdfs/P4TP4U.pdf

[26] Nuclear power plants in the U.S. today are 'light water' reactors that use water as a moderator to slow the speed of neutrons released during fission of the nuclear fuel. These reactors fission ^{235}U, which composes only 0.7 percent of natural uranium, to extract nuclear energy. Fast reactors allow neutrons to maintain higher energies and are thus capable of utilizing more of the nuclear fuel.

[27] Pauling received a Nobel Prize in Chemistry in 1954 for research on the nature of the chemical bond, and a Nobel Peace Prize for his advocacy of nuclear disarmament announced on the day the test ban treaty was signed in 1963.

and Fukushima forced long-term evacuation from substantial areas. Even though the areas evacuated, especially for Fukushima, are now recognized to have been much larger than necessary, this consequence is one that makes nuclear power a less desirable energy source, if a significant threat of such accidents is inherent to the technology.

The good news is that the newest nuclear reactors, including several reactors under development now, have designs that are inherently much safer. They can shut down in case of an accident such as an earthquake or tsunami, and they can keep the nuclear fuel cool without the need for external power. The possibility of an explosive accident is essentially designed out.

My favorite analogy is that of airplanes. When there is a major airplane accident, the public does not demand that we stop building aircraft. The Federal Aviation Administration (FAA) conducts an investigation to determine the accident cause, which can result in changes of aircraft design or airline operating procedures. The result is that air travel has become safer and safer.

George's reaction to that proposed analogy was the only time that I saw him slightly perturbed. He said that is the way it should be, but that is not the way it is with nuclear energy.

The Nuclear Regulatory Commission (NRC) is more political than the FAA. George defended NRC employees, saying that they were professionals doing a good job, but the Head of NRC was a political appointee and Democratic presidents appointed NRC Heads who were more-or-less anti-nuclear. Anti-nukes heading NRC? What a strange situation, if true!

How could that be? I should have asked more. I didn't have time. There are only 168 hours in a week. I had one foot in the environmental camp, and I had put one other foot in the nuclear power camp, e.g., signing up for a nuclear power chat group. My other two feet were in my government job as Director of the NASA Goddard Institute for Space Studies.

This two-footed strategy for trying to understand the energy-climate matter was similar to my political strategy, as an Independent. The main time I watch television is at dinner. Sometimes I flip between Fox and MSNBC (or CNN) to see what both sides were saying, but I get annoyed by the fact that they tend to synchronize their advertisements, which could thus not be avoided. So now we usually watch a half hour of PBS and a half hour of BBC America. Then we turn the television off, I go back to my computer and Anniek reads. Before going to bed I watch five minutes of MSNBC or CNN and five minutes of Fox. That's enough to be current.

I do not mean to equate the nuclear chat group and the environmental outlets. Most people in the nuclear chat group are trained in the scientific method. In contrast, my favorite environmental feed is EcoWatch. Their "Top News of the Day" gives an attractive, convenient summary of current news, including reposts from other outlets. However, they have one big problem: they post biased anti-nuclear propaganda indiscriminately, allowing it to masquerade as science.

When I asked George about the propensity of media to write scary articles on nuclear power, even though, despite the Three Mile Island, Chernobyl and Fukushima accidents, nuclear power had the best safety record of all major energy sources, he said "Follow the money." I thought he meant the fossil fuel industry, because it was common knowledge that they wanted to kill nuclear

Fig. 12. McKibben and Hansen leading a protest of the Capitol coal-fired power plant.[28]

power. Now I think that he meant something else, as I will explain later. I wish that I could ask George. I miss George, who died 7 October 2013.

To be clear: I support nuables and Nuable Portfolio Standards, for reasons I will soon explain. Nuables, more clearly described as Clean Energy, are nuclear power and renewables. Together they can get our planet back into the safe climate zone this century. More on that later.

Obama did not understand the urgency. He was not proposing actions with global effect. What are people to do in such a case, when they have no access to the President? We live in a democracy. We can write freely, we can testify, we can protest in the street.

Bill McKibben and 350.org organized a protest about the coal-fired power plant that Congress was using, to force attention to the climate issue. We expected to be arrested when we crossed a line, but when the police saw a few thousand of us, they decided to look away.

Students at Virginia Tech, where I gave a talk just prior to the 2008 election, were excited about Obama's candidacy and worked hard for his election. They wanted me to meet Larry Gibson, the little mountain man who refused to sell his property, thus preventing the coal company from bulldozing the mountaintop into a valley to expose a coal seam. So I was aware of Larry when I got a call the next spring, asking me to participate in a protest at Coal River Mountain.

I decided to go. Anniek drove down to West Virginia with me, in case I was arrested and needed to be bailed out. Larry Gibson drove us up the mountain to his cabin, which had been shot at by miners, who were disgruntled that he blocked mountaintop removal. A few dozen of us were arrested for "obstruction" (walking along the roadway). Larry and I did not plead guilty and pay a fine, instead asking for a trial with the threat of one year in prison, if found guilty. However, there would be no show trial: West Virginia dropped the case against us, years later. Our mountaintop removal protests, including arrests in front of the White House, had little effect.

Bill McKibben was more successful. He got thousands of people to protest against the Keystone XL pipeline, causing Obama to have second thoughts about approving the pipeline.

[28] Monastersky, R., 2009: A burden beyond bearing, *Nature* 458,1091-1094.

Stopping or reducing any of these carbon-heavy projects would be a big success, but much more important is policy from the top with global impact. That means support of a simple carbon fee and RD&D on carbon-free energies, especially the abandoned stepchild, nuclear power.

Obama, instead, chose an "all the above" policy, including expanded drilling for fossil fuels on public lands. Energy independence has been the goal of Democratic and Republican Presidents. Energy independence is possible – there's plenty of fossil fuels in the ground. All you must do is pretend you do not understand the implications for young people and other life on the planet.

Obama's policy was actually much worse than "all the above." With pressure from Senator Harry Reid of Nevada, Obama elevated Gregory Jaczko to be Chairman of the NRC in 2009. Jaczko was Reid's man. Jaczko was Reid's appropriations director and science policy adviser, until Reid pressured President George W. Bush to appoint Jaczko to be a Commissioner of NRC in 2005 by blocking 175 Bush appointees until Bush agreed to appoint Jaczko.

According to George Stanford, NRC Chairs appointed by Democrats tended to be subtly anti-nuclear. Over time, approval of a new nuclear power plant got longer and more expensive. This was consistent with the aim of many environmentalists, expressed to me, that it was best to stop construction of new nuclear power plants and phase out existing ones. However, note that the NRC deserves credit for safe operation of all U.S. nuclear power plants for over 50 years.

There was nothing subtle about Jaczko. He delayed the startup of a new nuclear plant by sitting on the paperwork for several months, thus increasing costs and time-to-build record. The NRC Inspector General accused Jaczko of "strategically" withholding information from his colleagues in an effort to keep plans for the Yucca Mountain nuclear waste repository from advancing. When the Fukushima accident occurred, Jaczko went into overdrive, advising the Japanese government to evacuate a huge area. This increased the accident's cost and more than 1000 people died, essentially because of heartbreak and stress from abandoning their homes.

No people died from radiation released at Fukushima, but many will die because of reactions to the accident. Worldwide shuttering of plans to use nuclear power increases fossil fuel pollution.

In a recent jaw-dropping op-ed, Jaczko asserts that he was pro-nuclear prior to Fukushima, but later concluded all nuclear power plants should be closed! Hmm. With that pronouncement, I think it is safe to neglect anything further that he says.

In March 2013 I retired from NASA. On 1 July 2013 I established the program Climate Science, Awareness and Solutions in the Columbia University Earth Institute, with Pushker Kharecha and Makiko Sato as staff members.

At the beginning we received generous support from philanthropists and were able to focus on climate science, the communication of that, and advocacy of actions to address climate change. We completed a substantial paper[29] that served as the scientific basis for the lawsuit Alec L v.

[29] Hansen, J., P. Kharecha, M. Sato, V. Masson-Delmotte, F. Ackerman, D.J. Beerling, P. Hearty, O. Hoegh-Guldberg, S.-L. Hsu, C. Parmesan, J. Rockstrom, E.J. Rohling, J. Sachs, P. Smith, K. Steffen, L. Van Susteren, K. von Schuckmann,

U.S. (We lost that case at DC District Court, but with a ruling that encouraged us to submit a new case with more emphasis on the rights of young people to 'due process' and 'equal protection of the law.' The new case is the current Juliana v. U.S.). Pushker and I also wrote a paper[24] showing how many lives were saved by nuclear power displacing fossil fuels.

Our early funding carried us a few years, but it soon became apparent that our assessment of nuclear power's contributions would affect our future funding and require us to spend a lot more time on fund raising. I am explicit about this topic because the phenomenon is widespread, not discussed, and has a potentially great impact on young people and future generations.

Scientists can see that if they say "renewables can provide all of our energy," they will be heroes. If, instead, they say that nuclear power likely is needed to phase out coal and clean the air, they may find it harder to gain research support and they may even be called "deniers." Scientists recognize this pressure, which may deter participation in the discussion, thus leaving the public with an inaccurate understanding of the consensus of the scientific community.

Philanthropists will assist organizations that support causes they believe in. That is their right. Unfortunately, from my perspective, events of the 1970s, when the baby boomer generation came of age, conspired to have an indelible effect on many people of that generation.

I will argue that a portion of the boomer generation has got control of Big Green, environmental organizations with annual budgets from donors of order $100M or more, to a degree that they have inordinate control of our national and even international energy and climate policies. This may be appropriate if they represent a majority of the membership. I doubt that.

I present evidence; you can form your opinion. It is important. There is talk of a Green New Deal, with some candidates favoring extermination of peaceful nuclear power. If elections turn that way, and if Big Green has its way, I weep for our planet, our nation, and our grandchildren.

Lee Wassermann of the Rockefeller Family Fund (RFF) was the person who rescued me when I realized that, if I spoke out against government energy policies during the Bush-Cheney administration, I should be careful not to use government support to prepare my presentations. Lee provided a small RFF grant, and then he arranged a larger contribution from an anonymous philanthropist. I never learned the identity of this generous "anonymous."

In 2013 Chris Arndt and I visited Lee in the RFF office. Chris was helping me line up support for the organization I was hoping to form, Climate Science, Awareness and Solutions. We left with the impression that we would likely get RFF support, and also that Lee would help find support from other philanthropists. However, later, when I returned, hoping to get firm commitments, Lee immediately pointed out that solar panels were becoming very cheap. He thought that renewables would be able to provide all electricity. I argued that such was unlikely to be the case, especially in China and India. Also, we, the West, burned much of their share of the global carbon budget, and we should not to try to force them down a specific energy path.

J.C. Zachos, 2013: Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature. *PLOS ONE*, **8**, e81468.

Both India and China are eager to have advanced, safe nuclear technology, especially to help clean up air pollution as well as to address climate change. However, the next time I visited RFF, Lee asserted that China was so overextended economically that they could not finance new nuclear power plants. Perhaps the organization RFF is opposed to nuclear power, I am not sure. However, it became clear that I could not expect to get funding assistance from RFF directly nor assistance in finding support from other organizations.

Antipathy of philanthropy toward nuclear power is understandable. Many of the principals came of age in the 1970s, a time of activism against nuclear power. A view of 200,000 people cheering at an anti-nuclear rally in New York City captures the spirit of the activism that succeeded earlier protests against the Viet Nam war. Nukes were government's latest misdeed.

The activists sing "give me the comforting glow of a wood fire" and "take all your atomic poison power away." The UN reports that more 10,000 people die each day from indoor air pollution, more than killed by nuclear power in history. Most air pollution deaths occur in China, India and other developing countries. Women, children and infants are the most exposed and affected.

Environmental organizations such as National Resources Defense Council, Environmental Defense Fund, World Wildlife Fund, Friends of the Earth, and Greenpeace are almost uniformly and deeply anti-nuclear, so it is no wonder that philanthropy follows their lead.

Ken Caldeira, Kerry Emanuel, Tom Wigley and I, in November 2013, wrote an open letter appeal to the environmental organizations to reconsider their opposition to nuclear power.

To those influencing environmental policy but opposed to nuclear power:

As climate and energy scientists concerned with global climate change, we are writing to urge you to advocate the development and deployment of safer nuclear energy systems. We appreciate your organization's concern about global warming, and your advocacy of renewable energy. But continued opposition to nuclear power threatens humanity's ability to avoid dangerous climate change.

We call on your organization to support the development and deployment of safer nuclear power systems as a practical means of addressing the climate change problem. Global demand for energy is growing rapidly and must continue to grow to provide the needs of developing economies. At the same time, the need to sharply reduce greenhouse gas emissions is becoming ever clearer. We can only increase energy supply while simultaneously reducing greenhouse gas emissions if new power plants turn away from using the atmosphere as a waste dump.

Renewables like wind and solar and biomass will certainly play roles in a future energy economy, but those energy sources cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires. While it may be theoretically possible to stabilize the climate without nuclear power, in the real world there is no credible path to climate stabilization that does not include a substantial role for nuclear power

We understand that today's nuclear plants are far from perfect. Fortunately, passive safety systems and other advances can make new plants much safer. And modern nuclear technology can reduce proliferation risks and solve the waste disposal problem by burning current waste and using fuel more efficiently. Innovation and economies of scale can make new power plants even cheaper than existing plants. Regardless of these advantages, nuclear needs to be encouraged based on its societal benefits.

Quantitative analyses show that the risks associated with the expanded use of nuclear energy are orders of magnitude smaller than the risks associated with fossil fuels. No energy system is without downsides.

We ask only that energy system decisions be based on facts, and not on emotions and biases that do not apply to 21st century nuclear technology.

While there will be no single technological silver bullet, the time has come for those who take the threat of global warming seriously to embrace the development and deployment of safer nuclear power systems as one among several technologies that will be essential to any credible effort to develop an energy system that does not rely on using the atmosphere as a waste dump.

With the planet warming and carbon dioxide emissions rising faster than ever, we cannot afford to turn away from any technology that has the potential to displace a large fraction of our carbon emissions. Much has changed since the 1970s. The time has come for a fresh approach to nuclear power in the 21st century.

We ask you and your organization to demonstrate its real concern about risks from climate damage by calling for the development and deployment of advanced nuclear energy.

It did not work. Environmental organizations reaffirmed their anti-nuclear positions. I was besieged by pleas to recant my heresy. I began to understand the depths of popular misconceptions about energy. These misconceptions have a greater influence on prospects for stabilizing climate than fossil fuel lobbyists and climate change deniers will ever have.

I decided to work over the holidays on an opinion article: Renewable Energy, Nuclear Power and Galileo: Do Scientists Have a Duty to Expose Popular Misconceptions? The article describes some misconceptions and suggests what key nations, individual citizens, and scientists can do.

One public misconception was thrust in my face after I gave a talk in Australia in which I suggested that nuclear power probably was needed to help phase out fossil fuels. My next talk was picketed by people asserting that nuclear power was killing a huge number of people and causing birth defects. When I queried them regarding the sources for these incredible assertions, I was told that Helen Caldicott was the source.

Here was a case where we scientists have failed to communicate well with the public. Helen Caldicott traveled the world espousing her "beliefs" about radiation. However, science is based on evidence, not beliefs. George Monbiot, a respected British journalist, explored in detail the sources of Caldicott's assertions. His resulting article, Evidence Meltdown, begins:

"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."

Monbiot's article in the *Guardian* is well worth reading. Among its jewels: "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."

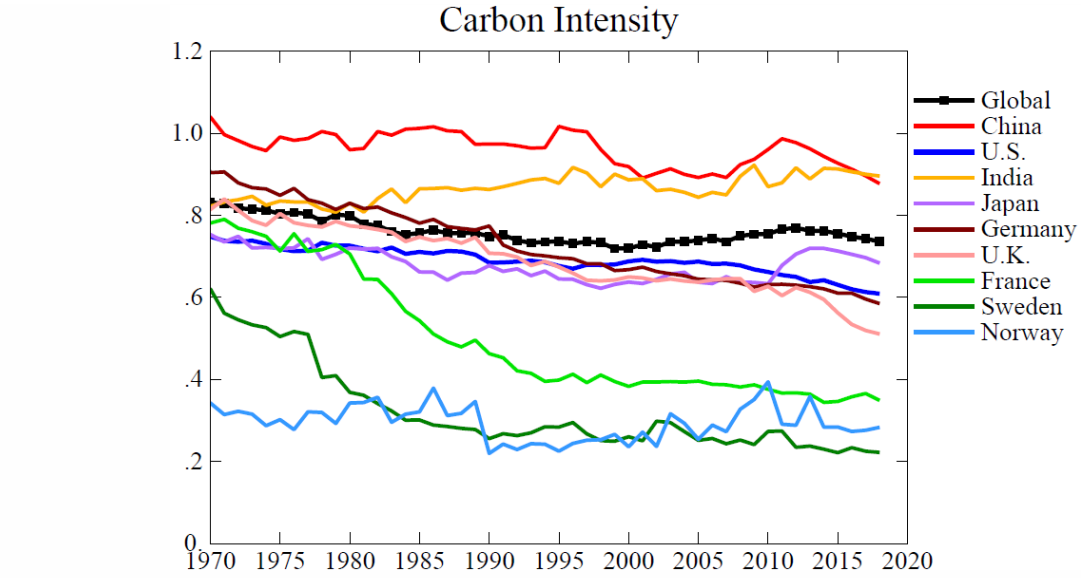

Fig. 13. Carbon intensity: fossil fuel emissions (GtC) over energy consumption (Gt oil eq.).

Another misconception is that cheap renewable energy will cause rapid phaseout of fossil fuels. Real world data do not support that conception. One revealing graph (Fig. 13) shows global and national carbon intensities.

The carbon intensity of a nation's energy consumption is a normalized measure of its reliance on high carbon fossil fuels. Sweden and France were the most successful in rapid transition to low carbon emissions, both accomplishing that via decisions to build nuclear power for electricity.

Sweden has an abundance of carbon-free electricity from nuclear and hydropower, so it can use electricity for much of its heating needs. The principal remaining requirement is to electrify transportation, e.g., via electric vehicles or liquid fuels produced from electricity.

The world as a whole, however, has made little progress in decarbonization. Indeed, the world is not decarbonizing; the world is carbonizing. Please reexamine the right half of Fig. 10.

The elephant in the room is the fact that, while most future emissions will arise from emerging economies such as China and India, their share of allowable carbon emissions already has been largely burned by the West. We cannot deny our moral responsibility, as revealed by Fig. 8(b). Even if we choose to deny any moral responsibility, we are still faced with stark realization that we live on one planet and will live one fate together.

This elephant, remarkably, is not one to be feared, once it is carefully examined. The actions required to phase down global carbon emissions are mutually beneficial in several ways. The requirements can be stated with regard to the major powers, the United States and China, because once these countries agree to cooperate, extension to near-global reach will be manifest.

Cooperation between China and the United States may seem unlikely today, yet when the eyes of future generations gaze back on this time – the time when human-made climate change became clear and dangerous – those future generations will only wonder why we were slow to work together. If we begin to cooperate soon, perhaps they will only be puzzled, but not unforgiving.

China and the United States, working together, could rapidly change the course that our planet is on. They could forge a path that moves us to a world with abundant affordable clean energy. Two actions are required for this vision to be achieved.

First, both nations should agree that fossil fuels must be made to pay their costs to society. This is an internal matter in the sense that each government should collect a rising coal-oil-gas carbon fee at their domestic mines and ports of entry and decide on the disposition of the revenue. However, wealth disparities among citizens are a growing worldwide problem that can be addressed by distributing the collected funds uniformly to citizens, which also spurs economic growth. In any case the governments must agree not to use the funds to subsidize exports.

Second, China and the Untied States should agree to cooperate in development of modern, safe nuclear reactors[30] that are less expensive than honestly-priced fossil fuel power plants. The cooperation could develop in stages, but it is even possible to imagine joint enterprises in which profits from sales to third party nations are shared.

Fortuitously, the Kissinger Institute on China and the United States sent me an invitation on 13 January 2014 to participate in a symposium on U.S.-China Relations, held in partnership with the Counsellors' Office of the State Council of the Peoples Republic of China. The Symposium, in Beijing in February, would focus on climate change and public health. Then we would travel to several cities to see Chinese progress in renewable energies and energy efficiency.

Donald Shriber of the Center for Disease Control and Prevention (CDC), the other scientist in our delegation, led our discussion on public health issues and I discussed climate. My talk (Beijing Charts) focused on recommendation of the two potential Chinese-American co-operations that are discussed above: mutual impositions of carbon fee & dividend and cooperation in development of inherently safe modern nuclear reactors.

I stayed up all one night to write an op-ed (The World's Greatest Crime Against Humanity and Nature). I am not sure if it was ever published in China; my focus in the op-ed on the local air pollution was not appreciated by everyone. The pollution was hard for me to ignore – I spent one evening in an emergency room (Sleepless in Ningbo), my asthma out of control.

In the op-ed I confessed that we, the scientific community, did a poor job of communicating the energy and climate situation to policymakers. Policymakers had somehow become persuaded that an all-renewables future was just around the corner. The enormity of the consequences of that disinformation was staggering to think about.

How to get governments to think strategically? I had to leave the Chinese cities tour early to get to Eugene, Oregon for an Environmental Law Conference focused on the Our Children's Trust lawsuit against the federal government, but before leaving China I began a correspondence with Richard Lester, Head of the Department of Nuclear Science and Engineering at MIT.

[30] Although 'fast' reactors, which can burn most of the nuclear fuel, should be included in the cooperation, the fastest payoff likely will be on passively-safe modular reactors that are largely factory-built. Multiple start-up companies are working on reactors that will shut down in case of an accident (such as an earthquake) and do not require external fuel to keep the nuclear fuel cool. Progress would be rapid if our countries worked together.

Maybe we could start something at the grassroots level, get scientists and engineers talking about what is needed to deal with the climate and air pollution problems. I suggested that we propose to Chinese colleagues a workshop on nuclear power at the East-West Center in Hawaii.

Previously I organized a workshop at the East-West Center on air pollution as a climate forcing, including scientists from China and India, with funding support from Gerry Lenfest. It was a good approach – Gerry imposed no requirements. We set the agenda and chose speakers based on the science, but we informed government officials, inviting them to attend and comment.

It was a good model. We could have a workshop on the potential for nuclear power to address the air pollution and climate problems, emphasizing the merits of working together with China. Per Peterson agreed that it was a good idea. Per, of the Department of Nuclear Engineering at the University of California at Berkeley, seemed to me to be the most brilliant of the stars that continued to shine in nuclear engineering, despite neglect of the field by the U.S. government.

Workshop planning had to wait, however. When I returned from the China/Oregon trip, I began to focus on writing a difficult paper, which I had put off for almost a decade. This paper was published more than two years later.[31]

Background information on this paper: One reason that I gave a public talk[32] in 2004 about the danger of climate change was my conclusion that IPCC scientists, including my friend Steve Schneider, were making an important mistake in their estimate of the dangerous level of global warming. Steve and his student Michael Mastrandrea estimated the dangerous level in a probabilistic framework. Their conclusions in 2004 were repeated in 2005 in Steve's 'inaugural' paper[33] in the *Proceedings of the National Academy of Sciences* upon Steve's election to the National Academy of Sciences. Using multiple 'reasons for concern,' they found that 50 percent chance of exceeding the dangerous threshold was reached at global warming 2.85°C relative to late 20th century climate, or 3.45°C relative to preindustrial temperature.

Such global warming was a prescription for disaster, I had concluded. Paleoclimate data showed that sea level was very sensitive to changes of global temperature. IPCC must have been aware of paleoclimate data, but they relied mostly on models. Also, they seemed fascinated by the year 2100 – they paid little attention to what might be happening beyond that year.

IPCC glaciologists, or ice sheet modelers, may not have been representative of all glaciologists – some glaciologists were getting worried about ice sheet stability. Lack of more public concern could be caused in part by scientific reticence.[34] ***A primary reason for reticence is that the penalty for 'crying wolf' is clear and immediate, administered via peer review of papers and***

[31] Hansen, J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, I. Velicogna, B. Tormey, B. Donovan, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. Legrande, M. Bauer, and K.-W. Lo, 2016: Ice melt, sea level rise and superstorms:Evidence from paleoclimate data, climate modeling, and modern observations that 2 C global warming could be dangerous *Atmos. Chem. Phys.*, **16**, 3761-3812

[32] Hansen, J., 2004: Dangerous anthropogenic interference: A discussion of humanity's Faustian climate bargain and the payments coming due, Distinguished Public Lecture, University of Iowa, 26 October.

[33] Schneider, S.H. and M.D. Mastrandrea, Probabilistic assessment of "dangerous" climate change and emissions pathways, Proc. Natl. Acad. Sci. 102, 15728-15735, 2005.

[34] Hansen, J.E., 2007: Scientific reticence and sea level rise. *Environ. Res. Lett.*, **2**, 024002

funding proposals. In contrast, there is no penalty for 'fiddling while Rome burns.' On the contrary, extensive caveats and calls for more research generate collegial praise.

I expressed concern about potential large sea level rise in my 2004 Iowa talk and in a paper[35] published in early 2005. That paper forced me to think about how the ice sheet would interact with the ocean. From paleoclimate data we know that a disintegrating ice sheet can send an armada of icebergs into the ocean. It takes a lot of energy to melt ice: 80 calories per gram.

This iceberg cooling effect on the ocean was not included in most climate models. Could it be an important oversight? Reto Ruedy, Makiko Sato and I started some experiments with our global climate model in 2006 to investigate that matter.

The climate model results were shocking. In such case, a scientist has a double reaction, as Sherry Rowland did when he and Mario Molina discovered that CFCs destroy ozone. When Sherry's wife asked how things had gone at the office that day, he responded something to the effect: "Great. But it looks like the end of the world."

What our model showed was shutdown of the overturning ocean circulation by midcentury, not only in the North Atlantic, but also in the Southern Ocean, surrounding Antarctica.

Wally Broecker predicted the possibility of North Atlantic shutdown of the Atlantic Meridional Overturning Circulation (AMOC), based on evidence of such events in the paleoclimate record. However, IPCC climate models did not find an AMOC shutdown for realistic greenhouse gas growth, only a modest AMOC slowdown that reduced regional warming in the North Atlantic.

Our model yielded strong cooling of surface water of the North Atlantic, and even more so of the Southern Ocean. Shutdown of the overturning circulation around Antarctica would be important. That overturning normally brings relatively warm water from intermediate ocean depths to the surface, where ocean heat is vented to the atmosphere and from there to space.

In our model this Southern Ocean Meridional Overturning Circulation (SMOC) shut down, thus turning off the escape valve for ocean heat. Therefore, the deeper ocean began to warm, with maximum warming at depth 1-2 kilometers. That is the depth reached by the ice shelves, the tongues of ice that extent out from the Antarctic ice sheet into the ocean.

Warming of waters abutting the ice shelves is ominous. As ice shelves melt, the land-based ice sheet would disgorge ice to the ocean. Melting of the icebergs would reinforce the process, as the cold, fresh water from icebergs is less dense than the salty deeper ocean, thus keeping the overturning SMOC shut down. Ice shelf melting would accelerate.

Rapid sea level rise would follow, due to this self-amplification. Earth's energy imbalance, caused by human-made greenhouse gases, would keep pumping heat into the ocean, providing energy to melt ice shelves and the growing volume of icebergs, until the easily available ice of Antarctica was exhausted. That easily available ice – sitting mostly in West Antarctica on

[35] Hansen, J.E. 2005: A slippery slope: How much global warming constitutes "dangerous anthropogenic interference"? An editorial essay. *Clim. Change* **68**, 269-279

bedrock far below sea level – is enough to produce a global sea level rise of several meters, making coastal cities dysfunctional, even though parts of the cities would stick above water.

When Earth's climate is close to equilibrium, that is when global temperature is stable, the sizes of the Greenland and Antarctic ice sheets tend to be stable. The ice sheets continually lose mass at their edges, as icebergs float away, but they gain a similar mass from snowfall over the interior of the ice sheet. Many climate models do not keep close track of all local energy exchanges as water changes phase, for example as icebergs melt, because those energy exchanges do not matter much if climate is close to equilibrium.

However, when Earth is undergoing a strong global warming trend, as it has been for the past several decades, we expect that the sheets will begin to lose mass. Ice sheet disintegration, we know from Earth's history, is a highly 'nonlinear' process, in other words, the mass loss begins slowly, but, as global warming continues to grow, ice sheet mass loss grows faster and faster.

But how fast? How soon could the habitability of coastal cities be threatened? Ice sheet models had ice sheets changing on millennial time scales. That was consistent with the envelope of sea level change on paleo time scales, the large glacial-to-interglacial changes caused by slow Earth orbital changes. However, paleoclimate data show that sea level sometimes went up several meters in a century, so the ice physics clearly allows fast response.

In my critique[34,35] of ice sheet model predictions, I gave reasons to believe that the ice sheet response time to human-made greenhouse gases would likely be much faster than suggested by the ice sheet models. Therefore, as an alternative to the ice sheet models, I decided to test several different rates of change and then compare results with real world observations.

A nonlinear process can be approximated by a doubling time during the period of rapid growth. Given current ice sheet mass loss rates, about five doublings are needed to reach meter-scale sea level rise. We know from Earth's history that multimeter sea level rise can occur in a century. Therefore, for our climate modeling experiments, we chose doubling times of 10 and 20 years. Meter-scale sea level rise is reached in about 50 and 100 years in these two cases.

Why did our model get rapid shutdown of the overturning ocean circulations, with cooling in the North Atlantic and even greater cooling around Antarctica, while other models did not? My first thought was that it must be the direct cooling effect of icebergs, the same way that ice cubes cool your Dr. Pepper. Each gram of ice, by melting, extracts 80 calories of heat from the water.

However, it was not that simple. We did experiments with the direct iceberg cooling omitted. In these experiments, cooling in the North Atlantic and Southern Ocean was reduced, but shutdown of AMOC and SMOC still occurred. So there was an additional reason that our model was more sensitive than other models to injection of freshwater onto the polar ocean surface.

What was the additional reason? I suspected that all ocean models, ours included, suffered from what I described as excessive 'sludge.' By this, I meant excessive small-scale mixing of ocean properties. Some unrealistic mixing occurs because of numerical error as a computer solves fundamental equations with finite differencing. A second likely source of sludge was in the way models estimate ocean mixing on scales smaller than the model's grid size – as you can imagine,

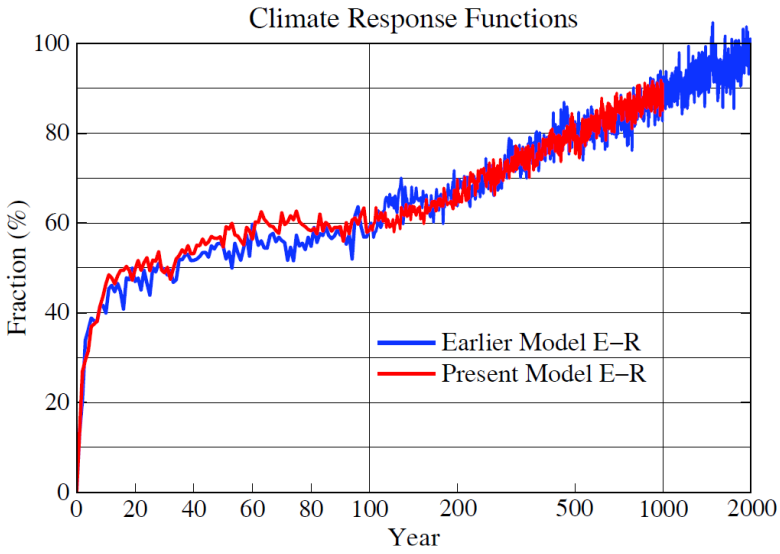

Figure 14. Climate response function, i.e., the fraction of the (fast feedbacks only) eventual (equilibrium) temperature change in response to a climate forcing (Fig. 4 of Hansen et al., 2016).[31] The time scale is linear for the first 100 years and logarithmic thereafter.

oceans do slosh about on small scales. However, turbulence is a hard, messy problem, and equations that approximate turbulence effects have a degree of arbitrariness.

My suspicion was that the turbulence parameterization caused excessive mixing. Such mixing makes global ocean models more 'well behaved.' The real world, however, is not so well-behaved. This 'sludge' problem might be less in our model, because Akio Arakawa and Gary Russell had gone to special effort to minimize unrealistic small-scale mixing. If this interpretation was correct, our model would be more sensitive than most models to freshwater injection onto polar oceans, but the real world would be even more sensitive than our model.

Proving this 'sludge' interpretation would be hard. I had evidence sufficient for strong suspicion, but proving the case likely would take several years. I decided to write *Storms of My Grandchildren* first, and then return to the modeling problem.

Let me describe the evidence for model 'sludge,' because this evidence also has implications for energy policy. The time required for global surface temperature in our model to approach its equilibrium response was very long, a few millennia. The 'response function' of the model (or real world) is defined as the fraction of the equilibrium (long term) global temperature change achieved as a function of time following imposition of a forcing.

Specifically, our model achieved almost half of its equilibrium response within a decade, but the remainder of the response was exceedingly 'recalcitrant'.[36] After 100 years the model's surface temperature still had reached only 60 percent of the equilibrium response (Fig. 14).

The recalcitrant portion of the equilibrium response seemed to be too recalcitrant, too slow. How did I know that? From Earth's energy imbalance. When climate models, including ours,

[36] Held, I.M., M. Winton, K. Takahashi, T. Delworth, F. Zeng, and G.K. Vallis, 2010: Probing the fast and slow components of global warming by returning abruptly to preindustrial forcing, *J. Climate*, **23**, 2418–2427.

were used to simulate climate of the past century, using best estimates for greenhouse gas and aerosol climate forcings, the models tended to find a current planetary energy imbalance of about 1 W/m^2 or slightly more. Observations suggested an imbalance about half that large.

The smaller observed energy imbalance implied that the real world comes to balance with the forcing more quickly than the model predicts. The energy imbalance test is not precise, however, because the results depend on the model's climate sensitivity, and results also can be jiggered via choice of aerosol climate forcing history, which is uncertain.

How did our model compare with other models? When I prepared the Bjerknes lecture at the American Geophysical Union meeting[37] I requested results of long climate simulations from three major modeling centers GFDL (NOAA's Geophysical Fluid Dynamics Laboratory), NCAR (National Center for Atmospheric Research), and the UK Hadley Centre. I found that these models were even somewhat slower than ours in achieving their equilibrium response!

My interpretation was that all of our models had excessive mixing of heat out of the upper wind-mixed layer. Our model seemed to have a bit less of this deep mixing, perhaps because of the computational schemes of Arakawa and Russell. The implication was that the real world was probably even more sensitive than our model, i.e., the shutdown of AMOC and SMOC, which occurred within several decades in our model, was likely to occur even sooner in the real world, under similar assumptions for the growth rate of climate forcings and ice melt.

That was the situation when I arrived home from the China/Oregon trip in early 2014. We began a new set of climate model runs and I vowed to camp out in my study until the paper was finished. It took more than a year to finish the paper, by which time the floor of my study had about 30 piles of papers on relevant topics, each with 10-30 papers.

It took nine months more to publish the paper. The very title of the paper, '*Ice Melt, Sea Level Rise, and Superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming is highly dangerous*,' incited an angry response from some reviewers, who considered it to be inflammatory and attention-grabbing.

Meanwhile, while I was quarantined working on the paper, new activities were initiated by a concerned person, who I only met on e-mail, in response to my Communications.

Steve Kirsch was fearless, imaginative, and determined to goad our laggard political system into action to address climate change. His style was audacious. He went straight to the highest level he could reach and asked why aren't you trying such-and-such? He reached high levels, perhaps because of his wealth or connections, but mainly because of his determination.

One of his power moves was to confront the Natural Resources Defense Council (NRDC) to try to persuade them to support modernization and expansion of nuclear power, America's largest source of clean energy. This was after the open letter that Caldeira, Emanuel, Wigley and I sent to the environmental organizations asking them to reconsider their opposition to nuclear power.

[37] Hansen, J., 2008: Climate threat to the planet: implications for energy policy and intergenerational justice, Bjerknes Lecture, American Geophysical Union, San Francisco, California, 17 December.

Bill McKibben suggested that I meet with the head of NRDC. I demurred – no meetings until *Ice Melt* was finished. Besides, NRDC's adamant response to our letter proved that their purpose was to tell me that I was off the reservation; so no progress was likely. Steve Kirsch pursued the opportunity of a lunch with the NRDC head, aiming to persuade them of the crucial role of modern, safe, carbon-free nuclear power for the sake of our children and grandchildren.

Kirsch failed. He reported that he was given three reasons why NRDC could not change its position on nuclear power. Numbers 1 and 2 were such-and-such. Number 3: NRDC would lose a significant fraction of their major donors. This blunt, honest response reminded me of when I was a kid and was told "you get three guesses and the first two don't count," which meant "the answer is so obvious that you should only need one guess."

Kirsch's reach extended to the President of the United States. Presumably because of a substantial contribution to the Democratic Party, Steve was able to meet Barack Obama, however briefly. Kirsch went with a prepared question: would the President be willing to "meet with Jim Hansen," who, Kirsch asserted, understood the problem as well as anyone and has "some viable ways to fix the problem?" Obama's response: he had already read my stuff (presumably meaning my book), but he would be interested in talking, if it were about policy (presumably meaning that he was already convinced about the reality of the climate threat).

Kirsch reported this news to me excitedly. Policy was the topic that I wanted to talk with Obama about. My response to Steve was we should pursue the possibility of meeting Obama, find out whether it was real or Obama was just being polite, as soon as the *Ice Melt* paper was finished.

On 22 June 2015 we finally submitted *Ice Melt* for publication. After I reported this to Steve, he tried valiantly to achieve the meeting with President Obama, but dolefully reported that he could not get through, the President was too well protected. Not so easily deterred, I reported the matter to Obama's Science Adviser, John Holdren, and sent him the *Ice Melt* paper. Holdren responded that it was a valuable paper, but he ignored my request to meet the President.

So who did the President listen to? It seemed to me that he listened to Al Gore and Democrats in Congress, including John Kerry. They were advocates of cap-and-trade, heavy subsidies of renewables, RPSs, and neglect of nuclear power, if not outright hostility to it.

But where did <u>they</u> get advice? I already mentioned the guru Amory Lovins. However, I believe that Big Green, the large environmental organizations, were even more influential. Al Gore went to Kyoto in 1997 carrying the cap-and-trade policy advocated by Environmental Defense. Although well-designed for national sulfur emission trading among U.S. utilities, cap-and-trade is cumbersome and ineffectual for trading among 200 nations.

NRDC had a major role in constructing the President's Clean Power Plan. The New York Times had a photo of NRDC lawyers sitting around a table making the plans. Earth does need good lawyers. I have attended meetings of NRDC and other Big Green organizations, e.g., with regard to efforts to minimize 'fracking.' The individuals are enthusiastic, dedicated, and doing as much good as they can (which is often a lot), given the constraints that they are working under.

Fig. 15. Humpback whale frolicking at Diablo Canyon nuclear power plant.

The problem is at the top of these organizations, in my opinion. Their leadership seems unable to take a global view. They do not appreciate the difference between cap-and-trade and fee-and-dividend and they are intransigent in opposition to even modern nuclear power. If their positions hold sway, it will guarantee that global emissions remain high for many decades and likely go even higher, because of emerging economies such as China and India.

Is it possible to affect the position of Big Green, say get them to support Clean Energy Portfolio Standards instead of Renewable Portfolio Standards? Maybe. In October 2014, in an Opinion[38] in the Des Moines Register, I suggested that the next time you receive a donation request from one of these organizations (accompanied by a photo of a cuddly animal or beautiful bird) toss it in the waste basket. Better yet, return the envelope with a note that you will consider a donation in the future, if they begin to support the best interests of young people and nature.

Don't bet on Big Green changing, however. Your contribution is likely small compared to the big donors, the wealthy Boomer generation patrons.

It is better to move on with a positive vision. Changing the course of a planet may seem like a tall order; indeed, it is a big, exciting, worthwhile challenge – things worth fighting for are seldom easy. Don't underestimate your ability to affect change. There are many ways to help.

If I were young today, given my bent for science, I would choose nuclear engineering, not space sciences. We must find a way for people to have abundant, affordable energy with a small environmental footprint. Even the nuclear technology of last century (which 'burns' less than one percent of the nuclear fuel) has the smallest environmental footprint of competing energies. Wildlife readily coexist with our nuclear power plants, such as Diablo Canyon (photo above).

[38] Hansen, J., 2014: Iowa roots: Speaking truth to power, Des Moines Register, 11 October.

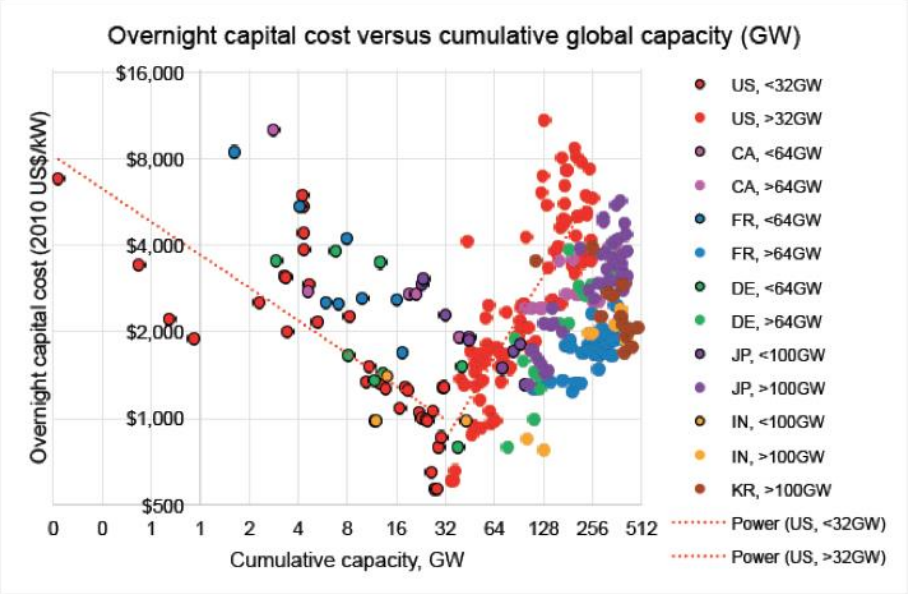

Fig. 16. Cost of installed nuclear energy versus cumulative installed capacity.

The exciting thing about nuclear technology is its potential in the near future. It has been shown that nuclear fuel can be 'sieved' from the ocean. There is enough fuel there, including continual leaching from the ocean floor, to last billions of years, i.e., the fuel is inexhaustible. That means that it is possible to dispense with surface mining, a process that resulted in some indigenous communities being left to deal with radioactive mine tailings.

We now know how to build nuclear reactors that are passively safe, which shut down in case of an accident such as an earthquake and that do not require external power to cool the reactor and fuel. Events such as the tsunami that hit Fukushima would not cause a nuclear disaster.

The primary challenge for future nuclear power is to drive down the cost, and there are good reasons to believe that it can be competitive with all other energy sources. In its early days the cost of nuclear power did decline with learning as expected (Fig. 16). The costs moved in the opposite direction as the power plants became larger, took longer to build, and encountered strong opposition from environmentalists. Examination suggests that the industry and government share in the blame for rising costs, but there is limited value in that debate.

Nuclear fuel is inexpensive, about $6 per MWe-hr including all costs (natural uranium, enrichment, fabrication, Nuclear Waste Fund fee), which translates to $0.56 per MMBtu. Today we consider gas at $6 per MMBtu to be very cheap. Gas could not compete with nuclear, if we built and operated nuclear plants at the same cost as fossil plants.

Construction and operating costs of nuclear plants are several times greater than equivalently complex non-nuclear facilities. There are no physics that require nuclear plant construction and operation to be more expensive than fossil plants, which is the reason to support innovation. Standardized modular reactors produced in a factory have potential for great cost reduction.

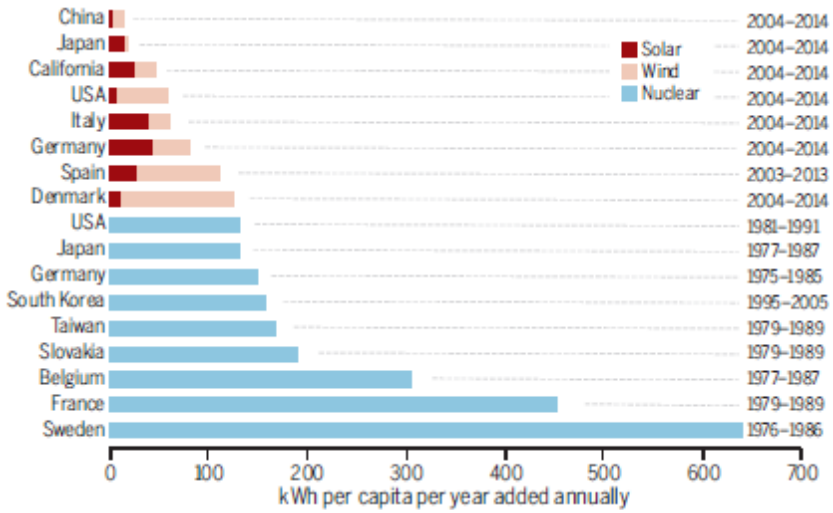

Fig. 17. Average annual increase of carbon-free electricity per capita in decade of peak scale-up.

That was the background for the U.S.-China workshop. My friend Junji Cao kindly agreed to host it in China, thus saving me the trouble of the fund-raising that would have been needed to hold it at the East-West Center. The workshop was held in 2015 a few days before Christmas.

Our workshop paper[39] published in *Science* shows that nuclear power has been the fastest way to build carbon-free power. With modular mass-manufacturing, future construction could be even faster, especially if there is technical cooperation between our nations. In the four years since our workshop, the rate of addition of renewable energies has increased markedly in many countries, but five of the six fastest cases of power addition are still those for nuclear power.

Facts matter. The argument of renewable advocates that nuclear construction is slow compared to renewables is false. Renewables and nuclear power are both needed. The most recent UN deep decarbonization scenarios all include major contributions from both renewables and nuclear power. They see no prospect of rapidly phasing down emissions without both energy sources.

Modern nuclear power did not obtain R&D support equivalent to the RPSs and subsidies that renewables enjoyed, yet much progress has been made. Large reduction of cost and construction time likely requires mass manufacture, analogous to ship and aircraft construction, which lends itself to product-type licensing. Passive safety features allow reactor shutdown and cooling without external power or operator intervention. Innovative designs use fuel more efficiently and produce less nuclear waste, directly supply heat for industrial processes, can reduce or eliminate cooling-water requirements, and can be ordered in a range of scales.

Deep decarbonization needed in China and India by midcentury can be accelerated by these innovative developments. Recent progress in the U.S. has been entrepreneurially driven, including small modular light-water, molten salt, gas-cooled and liquid-metal-cooled reactors. China has made major investments in several nuclear innovation projects.

[39] Cao, J., A. Cohen, J. Hansen, R. Lester, P. Peterson and H. Xu, 2016: China-U.S. cooperation to advance nuclear power, *Science*, **353**, 547-548.

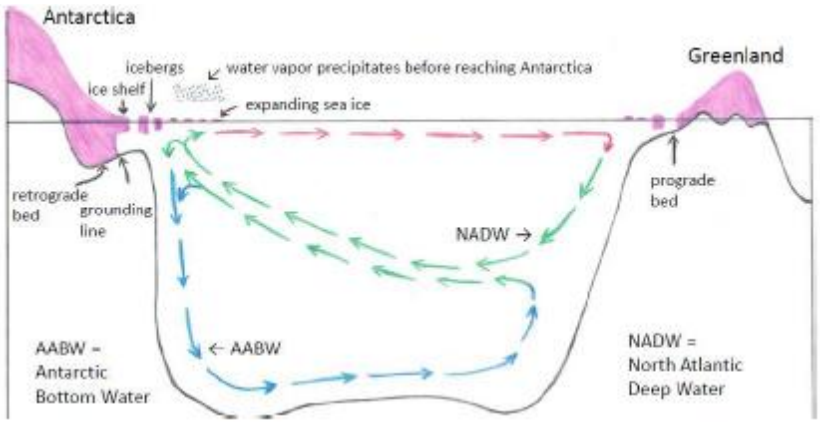

Fig. 18. Schematic of stratification and precipitation amplifying feedbacks. Stratification: increased freshwater flux reduces surface water density, thus reducing Antarctic Bottom Water (AABW) formation, trapping North Atlantic Deep Water (NADW) heat, and increasing ice shelf melt. Precipitation: increased freshwater flux cools ocean mixed layer, increases sea ice area, causing precipitation to fall before it reaches Antarctica, reducing ice sheet growth and increasing ocean surface freshening. Ice in West Antarctica and the Wilkes Basin, East Antarctica, is most vulnerable because of the instability of retrograde beds.

Cooperation among our nations in developing advanced nuclear power technologies has large potential benefits. We each have a major stake in the other's success in reducing its carbon emissions, and each has a major stake in the achievement of enhanced nuclear safety.

Our *Ice Melt*[31] paper was published in March 2016. We showed that growing meltwater from the ice sheets induces amplifying feedbacks (Fig. 18) that increase the melt rate of ice shelves and speed ice mass loss from Greenland and, especially, Antarctica. Based on paleoclimate evidence, we suggested that the characteristic time for accelerating mass loss, the doubling time, could be of order 10-20 years, if strong human-made climate forcing continues.

These doubling times lead to meter-scale sea level rise in 50-100 years, and several meters after one or two more doublings. The most vulnerable ice – in West Antarctica and parts of East Antarctica and Greenland – contains more than five meters of sea level rise, enough to make coastal cities dysfunctional. Consistent with these estimates, Pollard et al. (2015)[40] found that addition of a hypothesized treatment of hydro-fracturing and cliff failure into their ice sheet model increased simulated sea level rise from 2 to 17 meters in response to 2°C ocean warming and decreased the time for substantial sea level change from several centuries to several decades.

Empirical data for ongoing climate change and its impact on the ocean and ice sheets provides our best check on the physics. The best fit to the observed mass changes of Greenland and Antarctic ice (Fig. 19) suggests a doubling time of about 10 years, but the record is too short for meaningful quantitative assessment. Unfortunately, the GRACE satellite ceased functioning in 2016, but a new gravity satellite is now in orbit and should continue the record.

[40] Pollard, D., R.M. DeConto and R.B. Alley, 2015: Potential Antarctic ice sheet retreat driven by hydrofracturing and ice cliff failure, *Earth Planet. Sci. Lett.* **412**, 112-121.

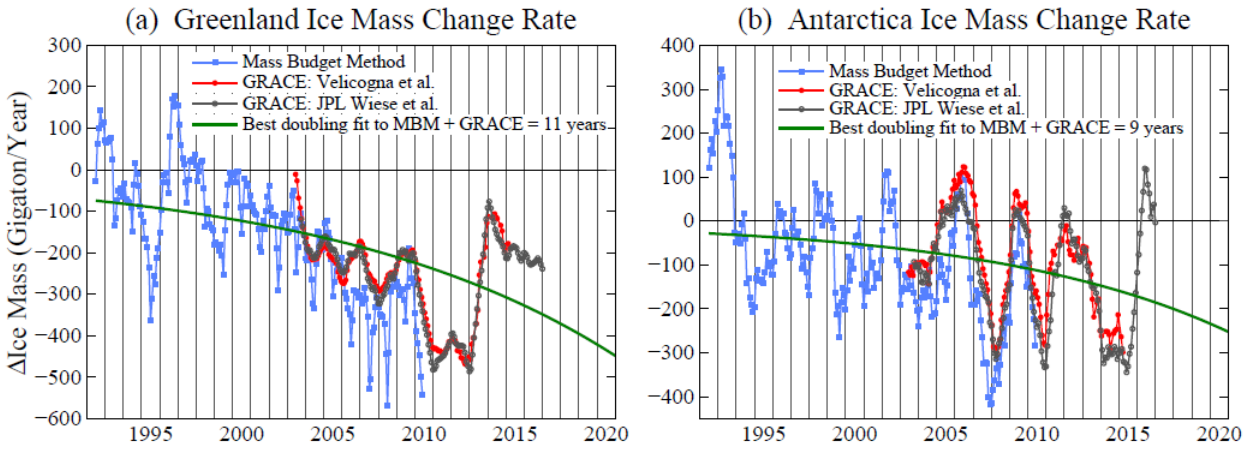

Fig. 19. Greenland and Antarctic ice mass change. GRACE data are extension of Velicogna et al.[41] (2014) gravity data. MBM (mass budget method) data are from Rignot et al.[42] (2011).

We cannot afford to wait until nature reveals the full response to human-made climate forcings. We need to understand the complete climate system as soon as possible. Like it or not, we are participants in a great geoengineering experiment that humanity is conducting on planet Earth. We are, indeed, already in the beginning stages of the resulting 'Fire on Planet Earth,' and we must create as much knowledge as we can to help young people achieve a bright future.

China and the United States initiated important scientific cooperation with the first joint meeting of the American Geophysical Union and the Chinese Academy of Sciences in Xi'an, China, on 17 October 2018. The topic of the conference was atmospheric aerosols. Charts for my aerosol review talk are available in PDF. The Powerpoint version (20 MB) is on my website.

Aerosols are second to greenhouse gases (GHGs) among human-made climate forcings, but of opposite sign, i.e., the net effect of aerosols is global cooling, estimated to be about half as large as GHG warming. If this estimate of the cooling effect is accurate, and if human production of aerosols were eliminated, the net forcing for warming would increase about 50 percent.

The aerosol climate effect is complex, because there are both reflective aerosols and absorbing aerosols (such as black soot), and because of the effect of changing aerosols on clouds. Aerosols are condensation nuclei for cloud drops; thus they can alter cloud brightness and cloud cover.

Understanding of aerosol processes has advanced in recent years via aerosol modeling, field observations, and satellite measurements. Yet aerosols are the largest source of uncertainty in our understanding of climate change in the past century and projections for the future.

Moreover, aerosols are chief among mechanisms proposed for purposeful, temporary climate management, in the event that unacceptable climate change looms. Potential interventions include injection of stratospheric aerosols or cloud seeding to increase Earth's reflectivity.

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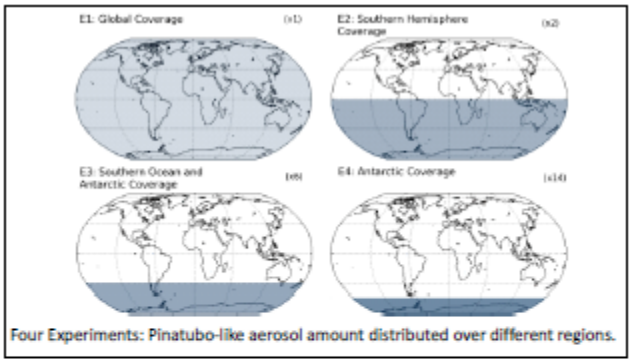
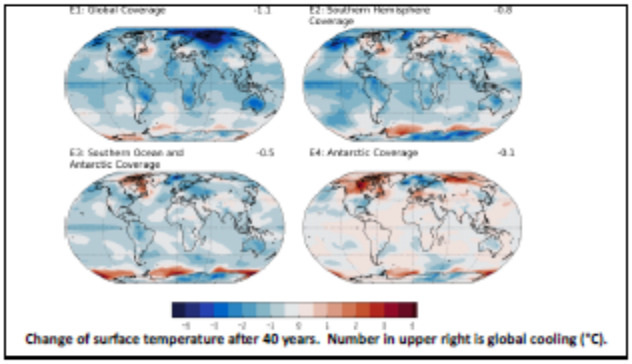
[41] Velicogna, I., T.C. Sutterley and M.R. van den Broecke, 2014: Regional acceleration in ice mass loss from Greenland and Antarctica using GRACE time-variable gravity data, *Geophys. Res. Lett*. **41**, 8130-8137.

[42] Rignot, E., J. Mouginot, M. Morlighem, H. Seroussi and B. Scheuchl, 2014: Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011, *Geophys. Res. Lett.* **41**, 3502-3509.



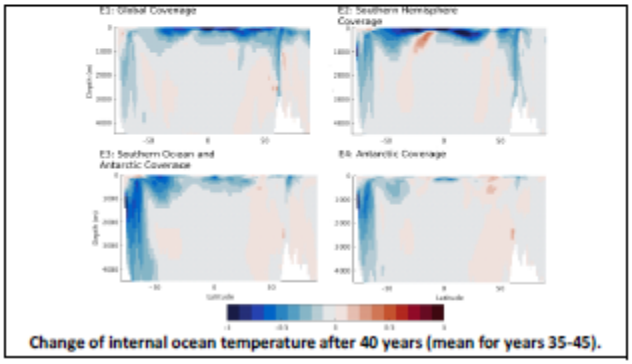
Slide 33

Craig Rye of my group (CSAS) has initiated four climate model simulations in which a Pinatubo aerosol amount is distributed uniformly over a fixed area, as illustrated here.



Slide 34

The global surface temperature change after 40 years with fixed aerosol amount is largest, minus 1.1°C, for the case with aerosols uniformly covering the globe.



Slide 35

The most important cooling may be that in the ocean, specifically the cooling along the coast of Antarctica at depths of a kilometer or so, where ice shelves are melting most rapidly.

This temperature change pattern is similar, and opposite in sign, to the calculated and observed ocean warming described in our Ice Melt, Sea Level Rise & Superstorms paper, which is caused by increasing CO2 and increasing fresh water injection. Such cooling may have the potential to slow or even stop sea level rise.

Fig. 20. Slides 33, 34, 35 of my [aerosol review at the AGU-CAS meeting in Xi'an].

Geoengineering is sometimes considered to be a bad word, but we are already well into a great geoengineering experiment, and for the sake of avoiding unacceptable consequences we had better understand all major knobs that humanity is already turning.

An indication of the sensitivity of climate to aerosols is shown by experiments with a global climate model in which stratospheric aerosols of the amount deposited by the 1991 Pinatubo eruption are distributed globally or sub-globally as shown in Slide 33 of Fig. 20.

Aerosols over the Southern Ocean and Antarctica yield a cooling of the Southern Ocean at depth (slide 35) that mirrors the warming by greenhouse gases. The enhanced escape of high latitude internal ocean heat to the atmosphere and space would slow the melting of ice shelves.

An alternative way to slow ice shelf melt is marine cloud brightening, to increase reflection of sunlight by clouds,[43] which can be achieved with a fleet of unmanned ships spraying sea water into the atmosphere, creating a fine mist of cloud condensation nuclei. This would cool Earth and reduce the flux of heat into the ocean. The extended period required to slow and reverse the growth of atmospheric CO_2 is likely to result in calls for such solar radiation management (SRM), especially if evidence of ice sheet collapse and rapid sea level rise increases.

Regardless of one's view on purposeful geoengineering, we need to understand what human-made aerosols are already doing to Earth's climate. The climate effect of aerosols will not be well understood until global aerosol properties are monitored accurately over a period of years. Precise measurement of aerosol and cloud microphysical properties must be made simultaneously, because aerosol effects on clouds are the largest source of uncertainty.

An aerosol monitoring program analogous to Keeling's CO_2 record is perhaps our greatest need for understanding human-made climate change. We know how to do it.

Ten parameters defining aerosol and cloud particle properties can be extracted from high accuracy (0.1% degree of polarization) measurements of the polarization of reflected sunlight measured at a wide range of scattering angles from the ultraviolet to infrared wavelengths.[44] This capability has been demonstrated with measurements from aircraft.

The best hope for achieving a Keeling-like record for aerosols lies is in the growing interest and capability of China in satellite monitoring of aerosol and cloud properties. The aerosol and cloud data can be optimized if the observations are made from a dedicated small satellite platform.

One of our activities in CSAS is to collaborate with scientific colleagues in China on aerosol and climate research. We have a track record in polarization studies,[45] including extraction of more precise information for aerosol properties on Venus[46] than exists today for Earth aerosols.

Cooperation of CSAS with China is natural, based on our past interactions. In our research proposal discussed below there are three Principal Investigators in China. Junji Cao, Director of the Key Laboratory of Aerosol Chemistry and Physics at the Institute of Earth Environment in Xi'an, has collaborated with us on aerosol research for more than a decade.[47] Zhengqiang Li, of the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, is a leader in China's satellite aerosol measurements. Jing Li was the most accomplished of our Columbia

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[43] Latham, J., et al., 2008: Global temperature stabilization via controlled albedo enhancement of low-level marine clouds, *Phil. Trans. Roy. Soc. A* **366**, 3969-3987.

[44] Mishchenko, M.I., B. Cairns, G. Kopp, C.F. Schueler, B.A. Fafaul, J.E. Hansen, R.J. Hooker, T. Itchkawich, H.B. Maring, and L.D. Travis, 2007: Accurate monitoring of terrestrial aerosols and total solar irradiance: Introducing the Glory mission. *Bull. Amer. Meteorol. Soc.*, **88**, 677-691.

[45] Hansen, J.E., and L.D. Travis, 1974: Light scattering in planetary atmospheres. *Space Sci. Rev.*, **16**, 527-610

[46] Hansen, J.E., and J.W. Hovenier, 1974: Interpretation of the polarization of Venus. *J. Atmos. Sci.*, **31**, 1137-1160

[47] Xu, B., J. Cao, J. Hansen, T. Yao, D.J. Joswia, N. Wang, G. Wu, M. Wang, H. Zhao, W. Yang, X. Liu, and J. He, 2009: Black soot and the survival of Tibetan glaciers. *Proc. Natl. Acad. Sci.*, **106**, 22114-22118.

University graduate students working at the NASA Goddard Institute for Space Studies, and she is now, at Peking University, one of the leading aerosol researchers.

Aerosols, the Ocean and Ice: Impacts on Future Climate and Sea Level. That was the title of the letter proposal[48] of CSAS to Schmidt Futures. Our proposal was miscast, as we planned to do science the old-fashioned way, focused on data. Futuristic analyses, including artificial intelligence, are also appropriate, but have limited potential in the absence of good data.

Simultaneous high accuracy global measurements of aerosol and cloud microphysics, e.g., promise to greatly improve our understanding of aerosol effects on clouds. Without such data, there are severe limits on how much knowledge can be squeezed from models.

We will continue to pursue support for this proposed research program, which would require of the order of $1M/year for five years. That cost is minimal because it leverages much more expensive work funded elsewhere. Global aerosol data would be obtained by China. Josh Willis, a collaborator on the proposed project, also requests no funding, as he has support for the ongoing Oceans Melting Greenland (OMG) project.

The proposed research includes use of multiple simultaneous data streams, including ocean heat storage measured by the Argo floats program and ice sheet mass balance changes inferred from gravity satellite measurements.

A crucial test of understanding will be obtained via analyses of ice sheet and sea level changes during the prior interglacial period, the Eemian. This study requires careful consistent dating of climate and sea level changes in both hemispheres.

Arguably, support of legal actions is the principal merit of the CSAS program. In addition to our role in the Our Children's Trust lawsuits, we have a growing involvement in multiple legal actions led by attorney Daniel Galpern.

Given the already excessive length of this note, I will defer discussion of these lawsuits to a future Communication, except for provision here of an eyechart[49] summarizing several cases in the past year and a short video[50] recorded by Stuart Scott at COP25 in Madrid, Spain.

The legal actions include lawsuits against the fossil fuel industry. My goal, however, is not to punish the fossil fuel industry, no matter how much they deserve it. My goal is to pressure the industry to become energy companies with focus on clean energy. Punishment and reparations are of much less interest than climate and sea level stabilization. These are immense tasks, and we need all the talent that can be mustered, including our captains of industry.

The ultimate, effective, pressure on the industry must be a rising carbon fee. So far, the industry has avoided an effective policy for carbon phasedown via its control of well-oiled politicians, but growing recognition of climate change and the threat of lawsuits may help change their position.

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[48] Aerosols, the Ocean and Ice: Impacts on Future Climate and Sea Level, CSAS, 15 September 2019.
[49] Hansen and Galpern, 2019, recent selected cases, 06 November.
[50] Galpern and Hansen, 2019, Sue the ********, Solve the Problem, COP25, Madrid, Spain.

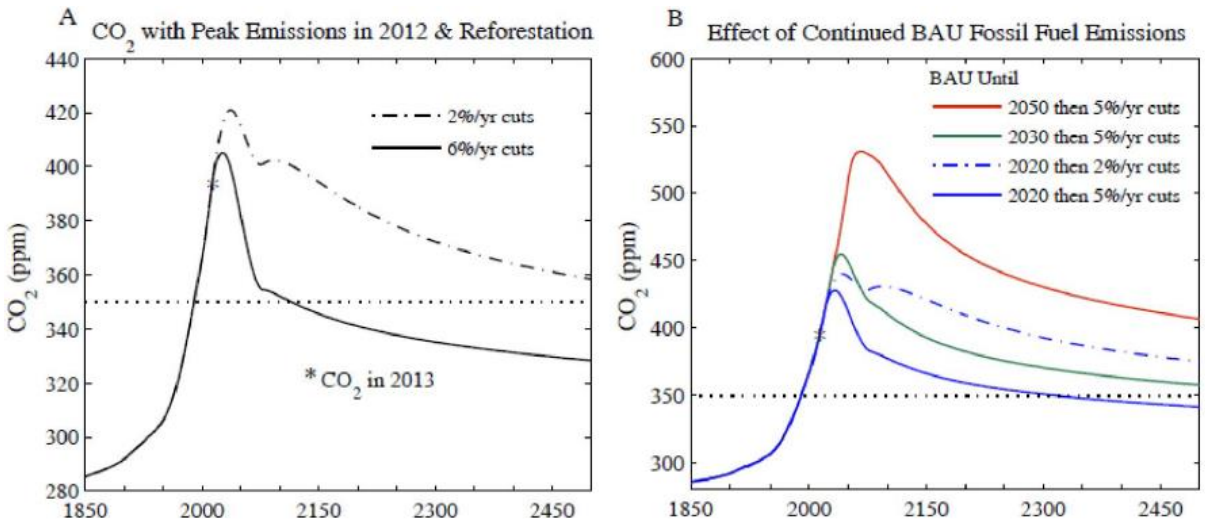

Fig. 21. Atmospheric CO_2 if fossil fuel emissions are reduced. (A) 6% or 2% annual cut begins in 2013 and 100 GtC drawdown occurs in 2031-2080, (B) effect of delaying emission reduction.

Solution of the climate problem is still conceivable, but it requires urgent planning. The magnitude of required emission changes can be appreciated based on graphs that we provided in the 2013 paper[29] prepared in support of the first Our Children's Trust lawsuit.

The blue, green and red lines in Fig. 21B show atmospheric CO_2 for cases in which 5%/year emission reductions are initiated in 2020, 2030 and 2050. In addition, a drawdown of 100 GtC into the soil and biosphere is assumed to occur over the period 2031-2080.

The maximum global warming is about 1.5°C if emission reductions of 2%/year begin in 2021. If emission reduction is delayed until 2030, the rate of emission reduction required is 5%/year to keep maximum warming to about 1.5°C. Global temperature is calculated assuming equilibrium climate sensitivity 3°C for doubled CO_2 and the climate response function of Fig. 14.

The required rate of global emission reduction rapidly increases as onset of reduction is delayed. The scenarios in part A of the figures, with emission reduction as small as 2%/year beginning in 2013, kept global warming far below 1.5°C, but such scenarios are defunct in 2019.

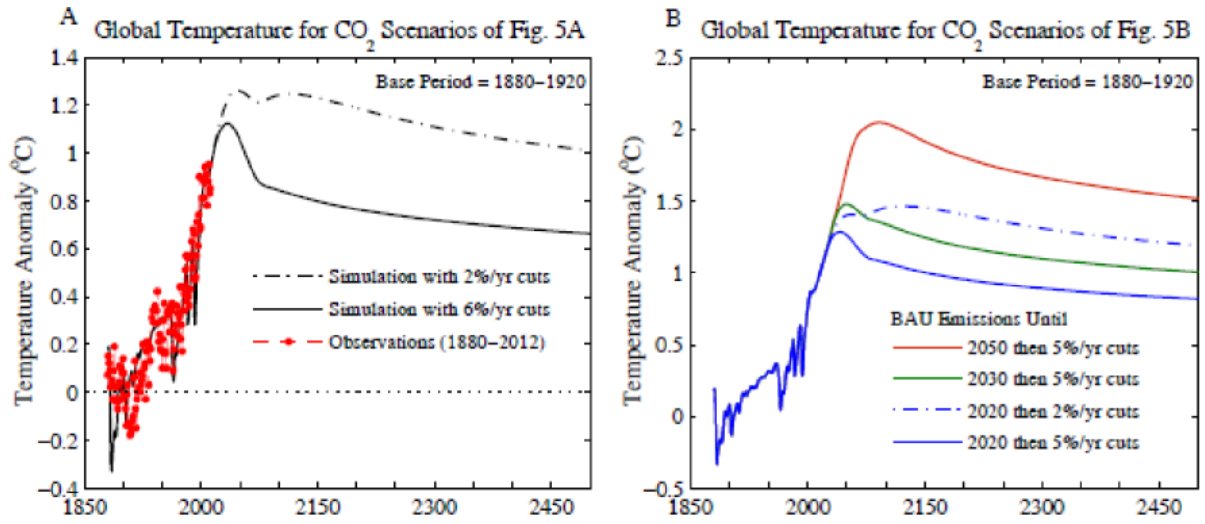

Fig. 22. Simulated global temperature relative to 1880-1920 mean for CO_2 scenarios in Fig. 21.

Summary: Our Green Energy Challenge. It was sobering to open the New York Times this morning (10 December) and read an op-ed by John Kerry and Ro Khanna, a California Democrat in the House of Representatives. I was disappointed to realize that another 15-year period of good, hard scientific data again yielded denial, a blindness to data.

In 2004, after 15 years of focusing strictly on science, I spoke out because of the inability of the Bush/Cheney Administration to appreciate the reality of climate change that was apparent in the data. It seemed that ideology affected their ability to see the truth and understand implications for fossil fuel emissions and energy policy. I recommended, to people who cared about the world they left for their children and grandchildren, that they should vote for John Kerry.

In 2019, after 15 more years of data, our politicians still do not appreciate the reality of data, such as that in Figs 1 & 9, compared with requirements revealed by Figs. 21 & 22. Some of Kerry's suggestions are useful, but they do not begin to address the challenge. Besides, many of the suggestions will be rejected outright by conservatives.

Political compromise is still possible, as shown by the new NAFTA (North American Free Trade Agreement). Why not suggest what economists and conservatives agree is the fastest way to phase down emissions, carbon fee and dividend? Such a policy is no cure-all, but it can make the price of fossil fuels honest and spur innovations needed to move us to a clean energy future.

In our fight for young people's future, China is not the enemy. China supported renewables at the behest of the West, and they helped drive down the price of our renewables. We also heavily subsidized renewables. Renewables are not the big issue, as shown by Figs. 1 & 9.

Large amounts of dispatchable (baseload) energy are needed, especially in countries such as China and India where energy use is still growing, but also in the West, where we want to electrify a larger fraction of our energy use. Renewables and energy storage will help, but we cannot phase out fossil fuels and 'fracking' without the help of modern nuclear power.

China and India would like modern nuclear power as an alternative to coal, but they will not massively replace coal burners until there is factory production of inherently safe reactors, as required to drive cost to or below that of coal and gas. There are issues to work out, as we noted in our *Science* paper,[39] but if we begin cooperation soon there are comparable mutual benefits and progress will be faster. If we dawdle much longer, China will proceed ahead on its own. India may become dependent on Russian (or Chinese) technology, and we may be left out.

Curiously, progress toward modern nuclear power has revived during the Trump Administration. The President may not even be aware of it, but NRC leadership is not hostile to nuclear power and may support some of the recommendations in our paper, such as a regulatory approach that encourages technical innovation in safety assurance as opposed to detailed prescriptive rules.

Support is thin and minimal, however, so progress is slow compared to what is needed. Some Green New Deal candidates talk about exterminating nuclear power. We may need a new party, but do we have time for that?

Young people must overcome a formidable barrier, if they want to enjoy the potential of fission power to provide clean energy and help stabilize climate. The formidability became clear subsequent to the "open letter" that Caldeira, Emanuel, Wigley and I sent to the leaders of environmental organizations, asking them to reconsider their opposition to nuclear power.

I was invited to appear on Amy Goodman's *Democracy Now* to explain the rationale for our recommendation. Amy is a sincere, hard-working, newscaster, so I agreed. However, the night before the early-morning program, I was told that a former NRC Commissioner would appear along with me. Remembering the admonition of George Stanford, I withdrew immediately.

I did not watch the program, but a colleague confirmed that it was an unwitting set-up, despite Amy's honesty. The former NRC Commissioner droned on with his lawyerly pitch about the dangers of nuclear power, an almost surreal exhibition of the status of our democracy now. Who would not believe the words of such an 'authoritative' voice?

A dear friend sent a message not long thereafter. She had helped with the intricacies of setting up my new organization, when I left the government – I would have been in trouble without her wise counsel. Now she wanted to provide counsel on my apparent advocacy of nuclear power. Would I be willing to talk with a friend, an ex-NRC Commissioner?

I nearly went into orbit. I decided to try to shock her into reexamining her position. First, I looked up Harry Truman's response to the music critic who criticized Margaret Truman's piano recital. Then I wrote a diatribe laced with pool-hall profanities, and ending with:

"What right do such slick-talking lawyers have to make decisions that hand my grandchildren a situation in which they can anticipate a life with greater difficulties and a mess caused by older generations? What right does he have to, in effect, use his position, as a fox in sheep's clothing, to try to make such clean energy options unavailable to parts of the world still in poverty, while he is living fat-and-happy in a country built on fossil fuels?

Yea, I would be willing to talk with him, in a back alley, but you had better warn him that I'm a good street fighter, and he is likely to come out needing a beefsteak for his eyes and a strong supporter down below." The last line was verbatim from Harry Truman.

The next time that I saw her, she cried and I felt like an idiot. My diatribe had not changed any minds. The matter was too fundamental to a lifetime of environmental work.

The difficulty of changing minds arose again recently. I received a message from a reporter in my hometown in Iowa. He told me about a wealthy person in New York who wanted to support my program. Was I willing to meet with her?

Of course. I was getting desperate to find financial support. I suggested a place to have lunch. I was surprised that she brought someone with her, an official in NRDC. Our conversation wandered around my various experiences while working for the government, until finally she got to her question: did I not regret some of the things that I said in the past?

I puzzled a bit, but could not think of an example. However, I admitted that I regretted that I lacked diplomacy, because that inadequacy had an adverse effect on some employees at the

NASA Goddard Institute. As my deputy there once noted, I tended to "blurt out the truth" without any sugar coating. It got us into trouble.

Specifically, I repeatedly criticized what I called a "Battlestar Galactica" approach to Earth observations, a focus on billion-dollar missions, at the expense of cheaper, faster missions. The consequence, it seemed to me, was retaliation. We had the two best people in the world in polarimetry measurements and analysis, but their careers were affected negatively, because I never succeeded in getting the small satellite mission that we wanted.

That brought our conversation to an end. As we left the restaurant, I walked north and they walked south. I doubted that I would hear from them again. I did not.

I was wondering as I walked, will scientific facts ever matter, or will positions be intransigent, based on beliefs? What if we fail to curb emissions, sea level rises faster, and a vast immigration problem arises? Will that change minds?

I doubt it. But perhaps changing of minds is not essential. Young people are getting fed up with the deal they are being handed. We need their idealism, their open minds, their honesty.

It is a heavy burden that we place on them. They will need to understand the situation. It is not just a climate problem. It is an energy problem. And a human rights problem.

Perhaps the best we can do is explain what we have seen and let them decide how they want to push the system.