The author and his granddaughter Sophie Kivlehan

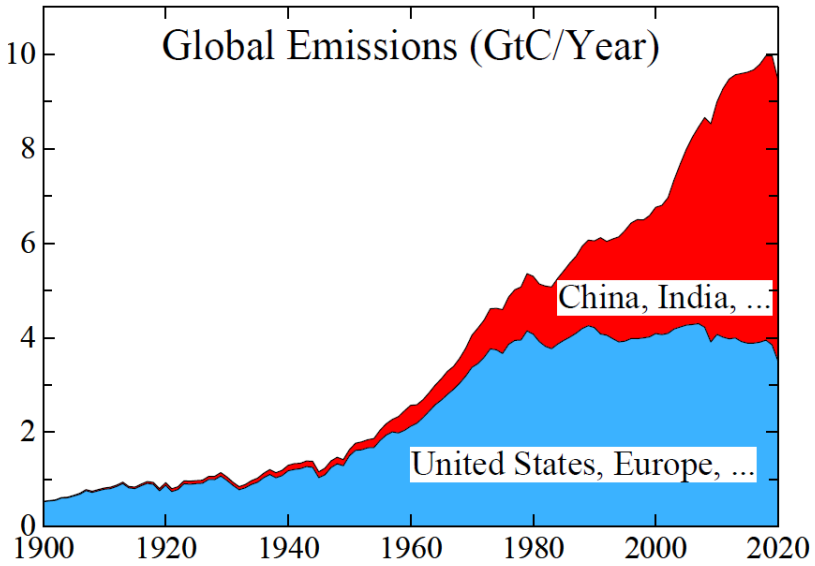

Fig. 47.1. Fossil fuel CO_2 emissions from mature (blue) and emerging economies.

Chapter 47. China and the Global Solution

China and the United States will likely determine the destiny of planet Earth. The outcome depends upon when these nations understand that their fates are inextricably bound, and they begin to work together wholeheartedly.

It was an honor to give the science talk on climate change at the *Symposium on a New Type of Major Power Relationship* in Beijing in February 2014.

The Kyoto Protocol and annual Conference of the Parties (COP) meetings for the United Nations Framework Convention on Climate Change showed that the world had no effective plan to address the climate threat. After the 1997 Kyoto Protocol, global fossil fuel CO_2 emissions shot up at an even faster rate than before (Fig. 47.1).

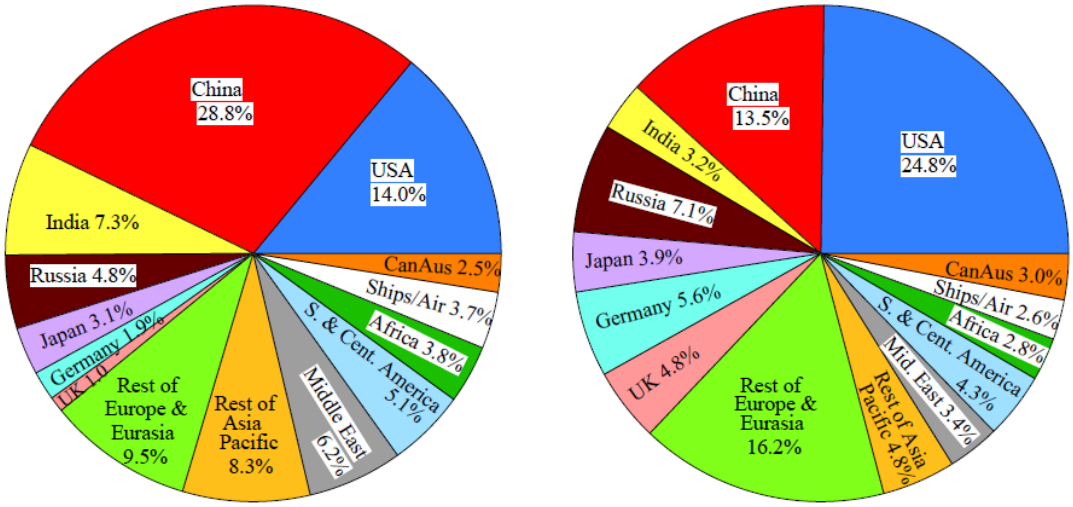

Figure 47.2. Left: fossil fuel emissions in 2018. Right: cumulative 1751-2018 emissions.[1]

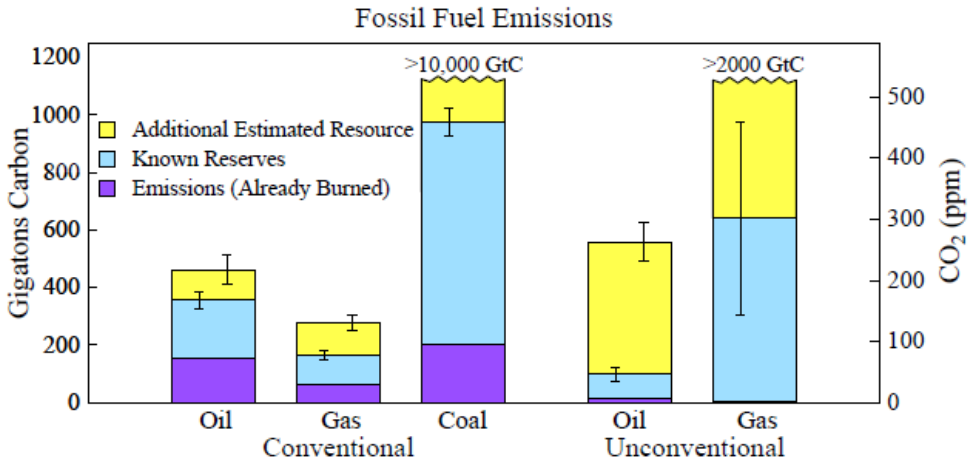

Figure 47.3. Fossil fuel emissions up to 2020 (purple areas).[2] 1 Gigaton of carbon (GtC) is a billion tons of C or about 3.7 GtCO₂. 1 ppm of atmospheric CO₂ is about 2.12 GtC.

Global warming is caused by worldwide emissions of greenhouse gases, mainly CO_2. Warming caused by CO_2 is proportional to cumulative emissions over time.[3] China is now the largest source of emissions, but the U.S. is most responsible for cumulative emissions (Fig. 47.2).[4]

A few additional facts suffice to frame the global energy and climate situation. So far, the world has burned only the portions of the fossil fuels shown by purple in Fig. 47.3. That was enough to raise living standards of most people in the West – and enough to raise global temperature close to dangerous levels. If we burn all the fossil fuels, we will melt all the ice on Earth and raise sea level almost 70 meters (more than 200 feet).

Washington, Beijing: we've got a problem! The entire Gulf Coast and East Coast of the U.S. is vulnerable to sea level rise, and China has hundreds of millions of people living near sea level (detail in charts). Shifting of climate zones, increasing climate extremes, and extermination of species are additional consequences that we must not accept – we can cooperate to avoid them.

We knew decades ago that burning all fossil fuels would create a different planet, with different shorelines, different climate zones, and with much of low latitudes uninhabitable. Yet the world continued on a path of business-almost-as-usual, burning more and more fossil fuels (Fig. 47.1), because energy is required to raise standards of living. People are willing to suffer pollution – temporarily – to raise living standards. Climate change seemed far away and uncertain.

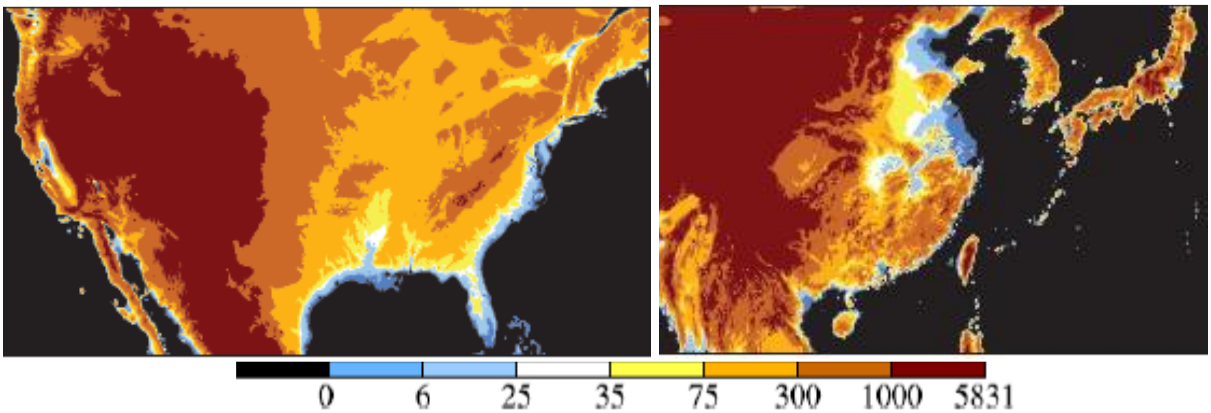

Figure 47.4. Areas under water for sea level rise of 6 m and 25 m in dark and light blue.

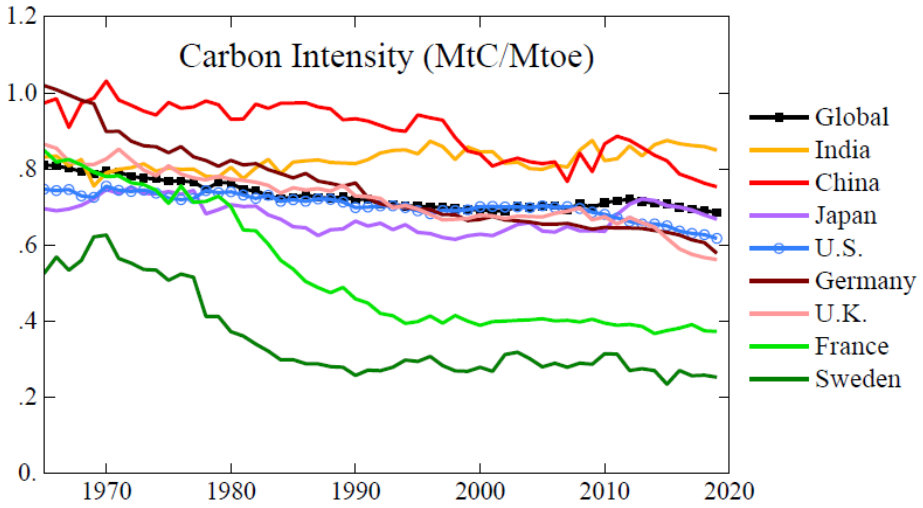

Fig. 47.5. Carbon intensity (carbon per unit energy) of global and national energies. MtC is megatons of carbon, and Mtoe is megatons of oil equivalent.

Implications of the climate and carbon facts are clear. The West burned most of the allowable global carbon budget. The East and West must work together now for mutual benefit. The urgent need is carbon-free energy sources to replace coal for burgeoning energy needs of the East. Such technologies can also help the West drive down their own carbon emissions.

Before leaving the U.S. to Beijing I posted an "*Opinion*" Renewable Energy, Nuclear Power and Galileo[5] on my website. My thesis was that renewable energy alone is unlikely to displace fossil fuels. The task of fully decarbonizing global energy is enormous. Nuclear power has the potential to play a significant role in that task, especially if we work with China.

The last chart of my presentation in Beijing (Fig. 47.5) was the carbon intensity of energy use in various countries and the world as a whole. That chart – fossil fuel carbon (GtC) emitted per unit energy (Gt of oil equivalent) – is arguably the best summary of how well the world is doing in moving to carbon-free energy. Atmospheric CO_2 may approximately stabilize when we reach a carbon intensity near 0.25,[6] but carbon intensity must be closer to zero to draw down atmospheric CO_2 and cool Earth to a level that stabilizes ice sheets and terminates tundra melt.

Unfortunately, global carbon intensity remains stubbornly high – almost 0.7 – in part because emerging economies, such as China and India, get much of their energy from coal. Moreover, progress in reducing carbon intensity is inadequate in most nations worldwide.

Sweden and France are notable exceptions. How did they do it? Once, when a Swedish minister showed a graph similar to Fig. 47.5, I asked how they achieved the rapid drop of carbon emissions between the mid-1970s and mid-1980s? The answer: "we introduced combined heat and power." Wonderful! This suggests that if we get the rest of the world to adopt combined heat and power, the global warming problem will be almost solved.

Eh, not so much. A Swedish engineer told me that the main reason was that Sweden completed 10 nuclear power plants in that decade. I interpreted the conflicting answers as a difference between scientists and ministers. The scientist looks at numbers and facts objectively, while the minister bears politics in mind, and the Swedish government had become quite anti-nuclear. Both answers were true, but the minister was misleading – hiding the crucial information.

My proposal for a new great power relationship consisted of two suggested cooperations.

First, China and the U.S. should agree to have rising domestic carbon fees. They would then be in a position to lead a global climate solution by imposing border duties on products from countries that do not have a carbon fee, thereby encouraging a global or near-global carbon fee.

Second, we should cooperate in development and deployment of 4th generation nuclear power to the point that modular nuclear reactors provide electricity cheaper than coal. By 4th generation I refer to all modern passively-safe reactors, whether thorium or uranium fueled – even nuclear fusion, which at long last is now closer than 50 years away.

As with renewable energies – which benefitted from renewable portfolio standards and subsidies for decades – it requires supportive government policies to drive the price of nuclear power down below that of fossil fuels. However, based on the amount of concrete, steel and other materials needed to build a reactor – and the price of nuclear fuel – it's clear that nuclear power can compete well with alternatives.

Reaction to my talk was positive, but there was little time for discussion. Audience members were scientists – members of the Chinese Academy of Sciences -- not government decision-makers. However, we believed that these scientists had the ear of government leaders.

Our itinerary had one-day trips to several cities and visits to factories making solar panels and windmills. The mayor of the first city visited – with a population of several million – told us of their extensive efforts in renewable energies. Their power, however, was 78% coal, 12% gas, 7% oil and 3% renewable. Their goal was to double renewable energy within a few years. Meanwhile their annual growth of energy use was 8.8%. Thus, growth of renewable energies could not cover growth of energy use, let alone phase out fossil fuels!

The global situation was irrational and untenable. The world was sailing toward an avoidable disaster, but nobody was taking needed action. At the end of my talk in Beijing I showed a cartoon with a large ship that resembled the Titanic heading for a great iceberg. The captain says "It's settled. We agree to sign a pledge to hold another meeting to consider changing course at a date yet to be determined."

I wanted to write an op-ed for a Chinese newspaper that might be read by Chinese leaders. Our time was fully subscribed, including dinners, so I stayed up writing[7] most of the night – yet the op-ed wasn't finished. The next evening, I developed an incessant cough from dripping in my lungs – air pollution had set off an asthma attack. A trip to the emergency room of the local hospital was efficient. In half an hour I had what I needed: a little bottle with 100 prednisone pills – a two-year supply at my usage rate. I paid the same as Chinese citizens: the equivalent of 85 U.S. cents, less than a penny per pill. Then I resumed writing.

My op-ed – titled "World's Greatest Crime against Humanity and Nature" – began: "As I peer through Beijing's impenetrable smog I feel nauseous. I have long been troubled by the injustice of human-made climate change to our children and grandchildren, which may soon constitute a tragedy of epic proportions. Now I stare in the face of another tragedy. Air pollution kills over 1,000,000 people per year in China… What makes me sick is the realization that climate change and air pollution were both preventable… And I know that we in the West bear a moral burden.

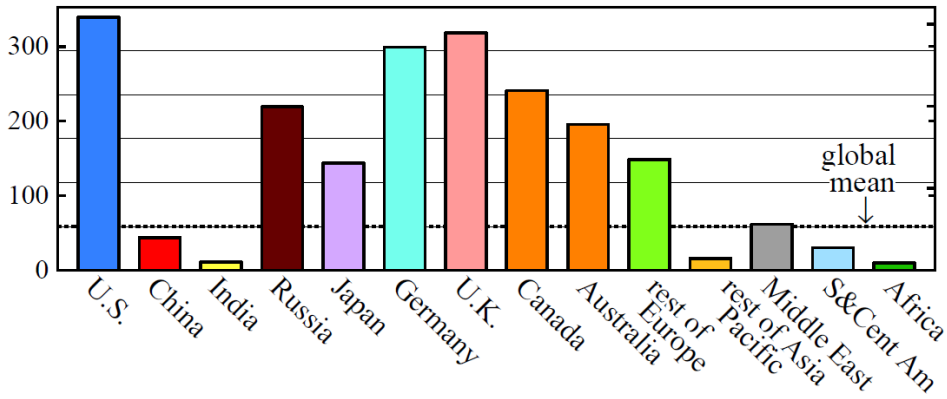

Fig. 47.6. Cumulative 1751-2020 carbon emissions (tons C/person; 2020 populations). Horizontal lines are multiples of the global mean.

We scientists have a special responsibility. We had knowledge 25 years ago that should have allowed climate change and air pollution to be manageable problems, not tragedies. However, we failed to communicate the implications well enough…"

Nations with well-developed economies bear an outsized responsibility for climate change (Fig. 47.6). If China and India follow a fossil fuel path like the West followed, we will all suffer the consequences. It makes sense that we all cooperate to avoid that pathway.

My op-ed noted the potential of modern nuclear power to replace coal-fired power. If nuclear power potential remains undeveloped, China will burn massive amounts of coal to raise living standards. Our children and grandchildren will then face near certainty of large climate change. We scientists should have made clearer the low limit on the global carbon budget – if disastrous climate impacts are to be avoided – and the fact that diffuse renewables cannot satisfy energy needs of countries such as China and India. My op-ed ended thusly:

"Recent events have been spiraling down so rapidly that I find it hard to sleep. Ex-President Clinton campaigns for a huge pipeline to carry Canadian tar sands, which would light a fuse to the dirtiest energy source on Earth, opening the way for unconventional fossil fuels that should be left in the ground. Dogged insistence by environmental groups that intermittent renewable energies are the only alternative to fossil fuels assures massive expansion of hydraulic-fracturing and helps lock-in long-term dependence on gas for electricity and carbon-intensive crude oil for vehicles. Yet my greatest frustration is with our own inability as scientists to clearly communicate the energy story. We could rapidly phase down fossil fuel emissions via a simple rising fee on carbon collected from fossil fuel companies, with funds distributed uniformly to the public, spurring efficiency and carbon-free energies, thus discharging our responsibility to future generations, other cultures, and other life on Earth. Instead, our governments subsidize fossil fuels and facilitate more-and-more invasive mining practices. Secretary of State John Kerry has offered to keep China informed of what we are doing about climate in the United States. If that is the best we can do, if we do not help China obtain the abundant, affordable carbon-free energy needed to raise living standards while leaving room on the planet for other species, I believe that our own children, and the world as a whole, are likely to look back on us as having been guilty of the world's greatest crime against humanity and nature."

The next day I sent an e-mail to Richard Lester, Chairman of Nuclear Engineering at the Massachusetts Institute of Technology: "For the sake of the planet, I think it would be better if China cut back on their plans for coal gasification and went more nuclear, provided…[8] I'm thinking it might be a good idea to have a workshop at the East-West Center at Univ. Hawaii. I have had workshops there twice, both on air pollution as a climate forcing. They were focused on the science of climate and pollution, involving people from China and India, as well as the U.S. and Europe. Now I'm thinking more on energy policy. I'm fed up with the fact that the government is not thinking strategically – and UN/IPCC is anti-nuke, or at least always has been. Stayed up all last night to write the attached op-ed – I haven't heard back yet from China Daily as to whether they will publish it. I must catch an early morning plane to Oregon."

My op-ed[9] was never published in China – perhaps it was too long or its focus on heavy air pollution in China was not appreciated. An abbreviated version of the op-ed – The Energy to Fight Injustice – was published in *Chemistry World*[10] upon invitation of an editor.

I thought I could complete the *Ice Melt* paper in a few months and then focus on organizing a workshop with American and Chinese scientists. Actually, writing and publishing *Ice Melt, Sea Level Rise and Superstorms* was an almost two-year struggle (Chapter 48), but by June 2015 I had a preliminary version of that paper, so I began to pursue the workshop idea.

Why go to the trouble and expense of organizing an international policy-relevant meeting? Why not leave it to the government? Because then it would be unlikely to happen. Politicians do not spend much time worrying about the long-term.

Indeed, I tried going via the system. When I testified to the United States Senate Committee on Foreign Relations – with regard to the Keystone XL pipeline – I made my testimony[11] more general, titling it Climate and Energy: Fundamental Facts, Responsibilities and Opportunities. This 13 March 2014 testimony concluded with two policy recommendations. The first was for carbon fee and dividend. The second was:

"The United States should cooperate with China to aid its transition to low-carbon and no-carbon energy sources, including the development and deployment of improved nuclear power technology. It is to everyone's disadvantage if China continues down a path of heavy carbon emissions, including, for example, extensive development of coal gasification. There is a strong complementarity of the contributions that the two nations could bring to such cooperation and there could be enormous benefits, not only to the two nations, but to the world."

The chance of politicians biting on this suggestion was slim. Some politicians stoke fear of nuclear power to aid reelection. The exaggerated fear of nuclear waste from power plants – which, with proper shielding harms nobody (Fig. 43.3) – is hyped, while poorly-contained waste from other energies is ignored. Waste from heavily-subsidized fossil fuels is spewed in the air freely. About 20,000 people per day die of outdoor and indoor air pollution – much of that pollution being waste from fossil fuel combustion. People drop like flies from that pollution – more than are killed by pandemics and wars combined – but politicians pay little heed.

Big green environmental groups and the media magnify public nuclear fears via sensational reports, while ignoring problems of other energy sources. Even 2nd generation nuclear power plants can be operated safely. The one serious accident in the U.S. – at Three-Mile Island – caused no deaths. Modern nuclear reactors that shut down in case of an anomaly and cool the

nuclear fuel without need for external power are our safest energy. Neither the Chernobyl nor Fukushima accidents would have occurred with modern nuclear power.

Scientists face pressure to agree with the incessant propaganda of big green and liberal media. Scientists who say that renewables can provide all of our energy tend to be popular and well-funded, even if their technical work is second-rate. However, in my opinion, if we scientists allow a foolish gamble – that renewables will provide all the energy the world needs – to be foisted on young people and to go unchallenged, we are being derelict in our duty as scientists.

Academic freedom of universities is a crucial asset. Even when I was in the government, I could put on my hat as an Adjunct Professor at Columbia University when that was useful, as I did when I organized workshops at the East-West Center in Hawaii.

In the summer of 2015, I began email discussion about a workshop with Chinese colleagues, mainly with Junji Cao – an expert on aerosol and climate science. Per Peterson – professor of nuclear engineering at the University of California in Berkeley – had good connections with nuclear science experts in China. By choosing the week of Christmas for the workshop, we found a time when all the essential participants from the West and from China were available.

Cao hosted the meeting in Hainan, China. Nuclear technology was the focus. The meeting was sobering on that topic. Neither country was ready to build modern nuclear power at a cost and time scale competitive with coal. Without such capability, coal will be the complement to renewables in emerging economies, and the climate problem remains unsolved. Thus, we discussed potential China-United States cooperation that would help bring nuclear technology to the level that is required for fossil fuels to be phased out over the next several decades.

A bonus at our meeting was participation of Kejun Jiang. I had heard Jiang speak in Beijing several years earlier, as he described China's long-term plan to improve energy efficiency and phase down pollution and carbon emissions. Jiang had deep knowledge of energy efficiency, renewable energies and alternative energy sources, but my most memorable impression was the fact that the Chinese government made long-term plans based on objective scientific advice.

Given the distance between Beijing – where Jiang was located – and Hainan, I thought it unlikely that Jiang would accept the invitation to meet during the workshop, but in fact he made the trip and we had lunch together. We agreed on the merits of fee-and-dividend, because it is more efficacious than cap-and-trade and easier to make near-global. Also, it would be popular because it helps address a growing wealth disparity that exists in many nations. We even talked about writing a joint paper on fee-and-dividend to help decisionmakers understand its merits.

We also agreed that a carbon fee high enough to drive out fossil fuels is not viable in absence of an alternative to fossil fuels for baseload electricity (available 24/7) that is competitive in price with the cheapest fossil fuel. The task of replacing fossil fuels is enormous, as shown by Fig. 47.7 for energy consumption of 71 nations tabulated by BP – ordered by the magnitude of energy use. Non-hydro renewable energies (green in Fig. 47.7) are a small portion of total energy use, and their growth has not even offset the growth of global energy consumption (Fig. 43.1).

Yet environmental groups pretend that renewable energies are on the verge of replacing fossil fuels, misleading young people about the actual situation. Worse, they spread fear of nuclear power, a potential partner of renewable energies. Utility experts say that, without nuclear power,

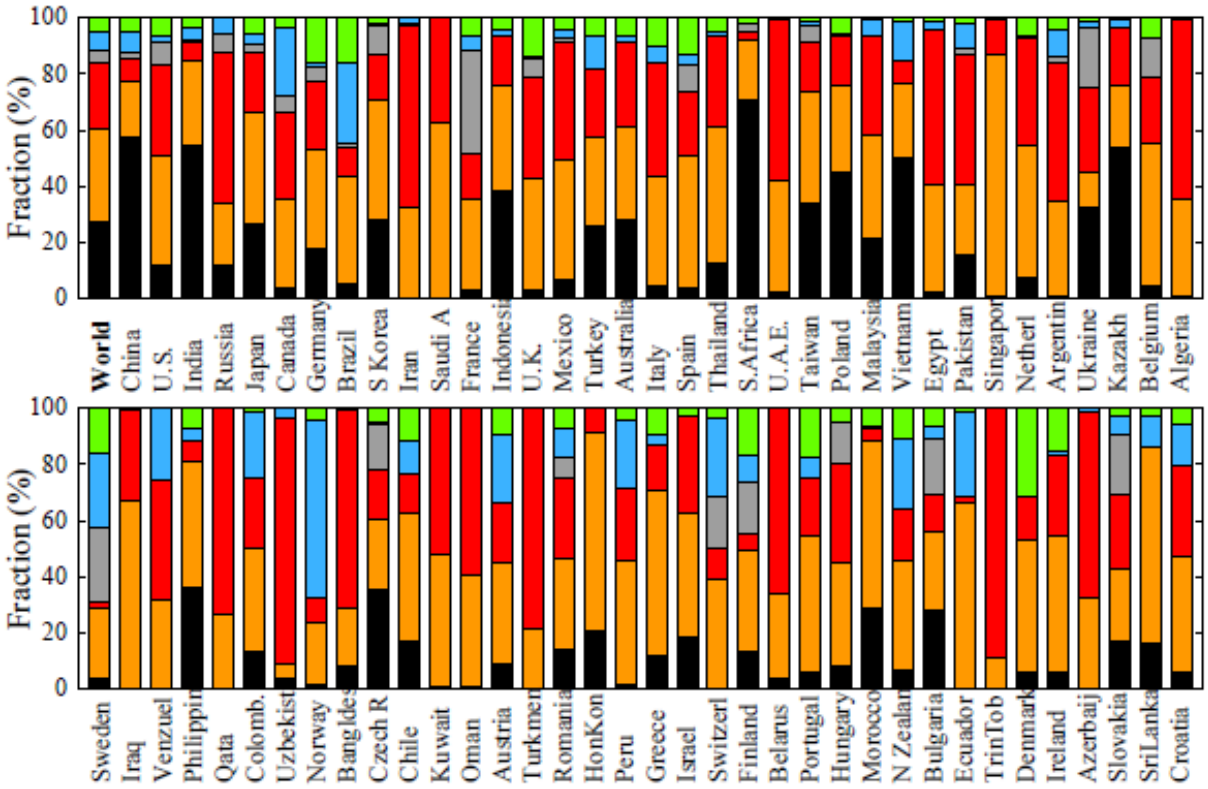

Fig. 47.7. Energy consumption (percent) in 2019 by fuel in world and 71 nations ordered by consumption in 2019: BP data (black = coal, orange = oil; red = gas; gray = nuclear; blue = hydro; green = renewable).

the complement of intermittent renewables during the next several decades will be gas (red in Fig. 47.7), which is almost as bad for climate as coal when effects on atmospheric methane are included. Batteries for energy storage may help smooth out intermittency of renewable energies, but breakthroughs in battery technology are required before this approach can contribute in a major way to global energy needs. Regardless of batteries, electric grids are expected to require a reliable dispatchable energy source – either fossil fuel or nuclear – that's available 24/7.

China and India have large, growing economies that depend on fossil fuels, especially coal. They are also global leaders in producing and installing renewable energies. Their enthusiasm for renewables is whetted by the opportunity to be global suppliers of renewable materials such as solar panels. Their own use of renewables is extensive and growing, but there is no realistic expectation that renewables will displace the need for baseload electric power.

Phase-out of fossil fuels in electricity production likely requires large expansion of renewable energies and at least a doubling or quadrupling of global nuclear power. The cost and time required for nuclear power plant construction must be reduced, if nuclear is to attain its potential. We concluded[12] that achievement of that goal likely requires mass manufacturing, analogous to ship and airplane construction, an approach that lends itself to product-type licensing to avoid the delay and cost associated with case-by-case approval.

Passive safety features are available that allow reactor shutdown and cooling without external power or operator intervention. Other innovative designs use fuel more efficiently and produce less nuclear waste, can directly supply energy to industrial processes that currently rely on fossil

fuels, can be ordered in a range of scales to suit a variety of needs and geographies, and can reduce or eliminate cooling-water requirements.

U.S.-China cooperation could accelerate nuclear energy innovation and the unit cost reduction that depends on production at scale, thus delivering benefits to both countries and the world. Floating nuclear plants – constructed in shipyards – could reduce cost and speed deployment. China's shipyards already build most of the world's large deep-water platforms and could be adapted to production of floating reactors.

Collaboration in technology will require government and industry in both countries to balance interests in cooperation and competition. Efforts to overcome obstacles to expanded U.S.-China cooperation in the development of advanced nuclear power technologies are justified by the large potential benefits. Each country has 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 in the other country and the rest of the world. In light of this potential, a review of U.S. export policies[13] is warranted with the goal of managing U.S.-Chinese intellectual property exchanges and creating stronger mutual support for vital international nuclear nonproliferation and security objectives.

China-U.S. cooperation has become more challenging since our workshop. U.S. President Trump declared that human-made climate change was a hoax, or, if it did exist, it was caused by China, despite contrary scientific facts (Figs. 47.2 and 47.6). Trump demonstrated the danger of ignoring science with his disastrous handling of Covid-19.

Common sense and our instincts for self-preservation eventually should make it possible for the U.S. and China to work together. U.S. scientists can facilitate that occurrence by maintaining and expanding personal and scientific interactions with Chinese friends and colleagues.

China doubtless can achieve clean carbon-free energy without U.S. cooperation, but working together could speed progress in both countries. Passively-safe reactors certified by the U.S. Nuclear Regulatory Commission might speed deployment of nuclear power at inland sites in China, where it is especially important to be certain there will be no radiation release.

Time is already late for affecting China's strategic energy planning, other than the possibility of advancing the time at which coal burners can be replaced by modern nuclear power. We should also work with other major emerging economies, especially India, whose population will soon pass that of China. In our paper based on the Hainan workshop, we noted our intention to include India and Indonesia in our next workshop.

The world is in a race between irreversible runaway climate change and the political changes required to achieve phaseout of fossil fuel emissions. We can still win that race. The next decade likely will determine the outcome.

The existential threat of runaway climate change has come into focus. The critical physical process is the disintegration of ice sheets that could raise sea level several meters, creating havoc for more than half of the world's largest cities. Together with deteriorating habitability of low latitudes, the massive emigration pressures could make the planet ungovernable.

Global fossil fuel emissions (Fig. 47.7) will not be phased out in one or two or even three decades. Emission reductions by mature economies in that period will be at least partly offset by growing emissions from numerous emerging economies.

Progress in technology in the next decade should make it feasible to begin phaseout of coal and a rapid transition to carbon-free electricity in all major economies. However, rapid transition will require cooperation between China and the United States.

China's leaders recognize the reality of the climate threat and the reality that China and the U.S. will remain in economic and ideological competition during the 21st century. Competitors need not be adversaries. Competition need not prevent the cooperation required to preserve habitability of our common home.[14] Fu Ying – former Vice Foreign Minister of China – has proposed[15] a way forward for the world's two leading powers. Current domestic politics in the two-party U.S. system tend to constrain potential cooperation, as one party paints itself as a champion against an adversarial China – thus making the other party hesitant to appear weak.

Facilitation of China-U.S. cooperation – even as we compete – is just one element in the race to achieve essential political change in the United States, as described in the penultimate Chapter 49: *Equal Rights and Opportunity*. Don't despair. Most people will agree that the changes are needed for multiple reasons and that they are possible to achieve. The political changes will address threats that have emerged to our democratic system, as well as the climate threat.

First, however, we must define – as well as science permits – the time scale that remains before runaway climate is out of humanity's control. That brings us to the all-important climate story, Chapter 48: *Ice Melt, Sea Level Rise and Superstorms*.

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[1] Hansen, J., M. Sato, R. Ruedy, P. Kharecha, A. Lacis, R.L. Miller, L. Nazarenko, K. Lo, G.A. Schmidt, G. Russell, et al.,: Dangerous human-made interference with climate: A GISS modelE study. *Atmos. Chem. Phys.*, **7**, 2287-2312, 2007.

[2] 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, 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, 2007

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[4] Hansen, J. and M. Sato, Regional Climate Change and National Responsibilities *Environ. Res. Lett.*, 11, 034009, 2016.

[5] Hansen, J., Renewable Energy, Nuclear Power and Galileo: Do Scientists Have a Duty to Expose Popular Misconceptions? http://www.columbia.edu /~jeh1/mailings/2014/20140221_DraftOpinion.pdf, 21 February 2014.

[6] That estimate assumes moderate continued increase of global energy use and no surprises with continued carbon uptake. A more elaborate estimate of the caron intensity at which atmospheric CO_2 ceases to grow does not seem warranted, because stabilization of CO_2 amount is only a way-station on the way to the near-zero carbon intensity that will be needed to draw down atmospheric CO_2 to a level that avoids dangerous warming.

[7] Hansen, J., Sleepless in Ningbo, www.columbia.edu/~jeh1/Documents/Ningbo.10March2014.pdf, 10 March 2014.

[8] The sentence ended with "provided…" as I knew that Lester would recognize reference to an e-mail that I sent to him the prior day in which I enquired about the possibility of MIT and other universities helping to train nuclear scientists and engineers to help assure safe operation of China's rapidly expanding nuclear fleet.

[9] Hansen, J., http://www.columbia.edu/~jeh1/mailings/2014/20140310_ChinaOpEd.pdf, 2014.

[10] Hansen, J., The Energy to Fight Injustice. Chemistry World, 23 July 2014.

[11] Hansen, J., Climate and Energy: Fundamental Facts, Responsibilities and Opportunities: Testimony to U.S. Senate Committee on Foreign Relations, 14 March 2014.

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

[13] Nephew, R., Reconsidering US Nuclear Cooperation Agreements, Columbia University Center on Global Energy Policy, https://www.energypolicy.columbia.edu/sites/default/files/file-uploads/NucCoopAgreements_CGEP-Report_032420.pdf, 2020.
[14] Even in the "cold war" between the US and USSR, there was important cooperation and scientific interchange.
[15] Ying, Fu, Cooperative competition is possible between China and the U.S., New York Times, 24 Nov. 2020.