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Zero-C by 2050?

Gates charts eliminating greenhouse gas emissions

Fifty-one billion tons of greenhouse gases. That's how much planet Earth emits into its atmosphere every year. Avoiding a future climate disaster requires that this be reduced to zero by 2050. In his introduction to *How to Avoid a Climate Disaster: the Solutions We Have and the Breakthroughs We Need* (Knopf, New York, 2021) Bill Gates relates how he first became aware of this from encountering the problem of energy poverty in conjunction with his foundation's work in global health. He also learned that this means that the energy sources used by planet Earth must be "clean."

This realization led him to take some actions on his own. He sold all his investments in fossil fuels, bought sustainable fuel for his jet, and purchased carbon dioxide offsets. In conjunction with COP21 (the Paris Climate Accord) he attracted 28 fellow investors to form the Breakthrough Energy organization. That all the miseries from COVID-19 have reduced greenhouse gas emissions by only 5% shows that reducing them to zero will be hard. But not reducing them to zero, he writes, would be a catastrophe. By using today's technology and the additional breakthroughs we'll need to achieve along the way, Gates believes that we *can* do it, and he has written this "how to" book to show us how to accomplish it.

In his first chapter Gates points out what is already known, that greenhouse gases in the atmosphere absorb infrared radiated by Earth and re-emit half of it back to Earth, thus warming Earth's surface and atmosphere. But this temperature increase has many consequences that vary from place to place and don't always vary linearly with the increase in temperature. Among them are 1) wetter and more intense storms, 2) more frequent and severe droughts and wildfires, 3) rising sea level, 4) reduced range of wildlife habitat, 5) mixed results for plant growth, 6) less coral and less dissolved oxygen for seafood, 7) increased range for mosquitoes and malaria, and 8) heatstroke from saturated hot air that doesn't allow evaporative cooling. He considers how this can affect a

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SNC-Lavalin Engineers Net Zero for Canada

In December 2019 the Canadian government announced plans to achieve "net zero" greenhouse gas emissions by 2050. These plans have now been charted by SNC-Lavalin in a 100-page report, *Engineering Net Zero*, released in March 2021. This goal "has the potential to effectively end Canada's contribution to global warming and help position Canada as a global leader in low-emission technologies and practices across all economic sectors. The enormous changes required will impact every aspect of our lives, from the way we travel, heat our homes, and ensure food and health security for our communities, to the ways we generate our power, operate industrial processes, and responsibly tap into our rich natural resources – every aspect of our lives will, in some way, be touched," the report begins. Doing nothing would allow sea level to rise and more extreme weather events, both leading to greater flooding, lead to an increased global temperature between 4°C and 5°C by 2100, and foster biodiversity loss.

Because greenhouse gases are mostly emitted in transforming energy sources into forms to meet human needs, the report begins by portraying the present pattern of these energy transformations in Canada. They currently emit 0.729 gigatons of carbon dioxide equivalent annually (of the 51 gigatons cited by Bill Gates in *How to Avoid a Climate Disaster*), which is a reduction from

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Commentary: It's Really Going to Happen!

When I began my teaching career at The Calhoun School amid the Arab Oil Embargo of 1974, the overriding concern was how to find enough energy to run our cars. The United States no longer produced enough oil to do this domestically, and we sought alternatives that weren't dependent on hostile areas of the world. The one fossil fuel the United States had (and still has) plenty of was coal, and under the Carter Administration a Synthetic Fuels Corporation was set up to explore the feasibility of producing gaseous and liquid fuels from coal on an economically viable basis. The tar sands known to be abundant in Canada (a friendly neighbor) were also considered.

Already into education about energy issues from teaching students about the Arab Oil Embargo, I participated in the summers of 1978 and 1979 with NSTA's Project for an Energy Enriched Curriculum with other like-minded teachers to develop curricula to teach students about various timely energy issues. One of them was the warming of Earth's atmosphere from the carbon dioxide emitted when fossil fuels are burned. I had learned about the greenhouse effect from carbon dioxide (and other gases whose molecules contained more than two atoms) at the Summer Institute in Space Physics in 1962, but I hadn't given any thought that human addition to the carbon dioxide in Earth's atmosphere would pose a threat to the planet.

Apparently no one else did then, either, but the steady and increased growth of carbon dioxide in Earth's atmosphere beginning in 1980 caused some to sit up and take notice that instead of trying to find enough oil to drive our cars we had better look around for an alternative that didn't add more carbon dioxide to the atmosphere. At the workshop on "The Role of Nuclear Power" I attended at Washington and Lee University in June 2007 they circulated a paper co-authored by James Hansen that the only fossil fuels we could "afford" to burn without reaching a danger point in atmospheric carbon dioxide concentration was the natural gas and oil known to be in the ground (it was listed as resource #3 in our Fall 2007 issue). With the onset of fracking and extraction of oil from the Albertan tar sands, we are already destined to go beyond this, and now the consequences of climate change from global warming are a feature of daily newscasts.

Then visionary authors started to describe ways we could deal with the carbon dioxide conundrum – by using renewable energy sources, primarily solar and wind, which had recently become economically competitive. Arjun Makhijani's talk to the American Association of Physics Teachers, based on his book, *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy*, was covered in our Fall 2007 issue and the book was reviewed in our Winter 2008 issue. David McKay's *Sustainable Energy – without the hot air*, was described in detail in our Fall 2009 issue; and *Our Renewable Future: Laying the Path for One Hundred Percent Clean Energy*, by Richard Heinberg and

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The TEACHERS CLEARINGHOUSE FOR SCIENCE AND SOCIETY EDUCATION, INC., was founded at The New Lincoln School on 11 March 1982 by the late Irma S. Jarcho, John L. Roeder, and the late Nancy S. Van Vranken. Its purpose is to channel information on science and society education to interested readers. To this end it publishes this *Newsletter* three times a year. Thanks to funds from tax-deductible contributions, the Clearinghouse is happy to be able to offer its services for a one-time nominal charge. In order to continue offering its services for a nominal charge, it also solicits underwriting of its publications by interested corporate sponsors. All correspondence should be addressed to the editor-in-chief at 17 Honeyflower Lane, West Windsor, NJ 08550-2418 or via e-mail at <JLRoeder@aol.com>.

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Jacobson writes text for 100% renewable energy

In our Fall 2017 issue we reported that a quartet headed by Mark Jacobson had published two years earlier a paper claiming that all the energy needs of the 48 contiguous states could be met renewably between 2050 and 2055. Two years later a team headed by Christopher Clack rebutted those claims, and then each team engaged in a second round of claim and counter-claim.

Now Jacobson is bringing his message to the masses in the form of a textbook, *100% Clean, Renewable Energy and Storage for Everything*, published by the Cambridge University Press. As part of its publicity of the book, the publisher has provided a video of the author describing the book and why he wrote it.

Jacobson began by dating the reason for writing the book to his awareness of Los Angeles air pollution at age 13 and his determination to right it. Unfortunately, he continued, there was no college major to pursue this, so he pursued civil engineering, where he benefited from two courses taught by Gil Masters, who had written books on renewable energy, and got an M.S. in environmental science.

Jacobson then expanded what he had learned into a global climate model and found that black carbon was as big a problem as carbon dioxide, looked into wind energy and wrote a paper with Masters that wind could replace a lot of coal. He expanded this study to include other renewables, nuclear energy, and carbon control and sequestration (CCS) to evolve his wind-water-solar (WWS) strategy. He worked with Mark deLuckey on whether the world could be powered by WWS and found that the answer was yes, but with social and political barriers, even by 2030, as advocated by the Green New Deal. In 2010 Jacobson established the Solutions Project (solutionsproject.org) to educate the public on 100% renewable energy, which led to writing his book.

Jacobson observed that energy accounts for 75-80% of the world's greenhouse gas emissions and 90% of its air pollution and that we need to reduce greenhouse gas emissions 80% by 2030 and 100% by 2050 to avoid a further global temperature increase of 1.5°C. Thus, he begins his book with a chapter titled "What Problems Are We Trying to Solve?" – with subheadings of Air Pollution, Global Warming, and Energy Insecurity. This is followed by a chapter on the "Wind-Water-Solar and Storage Solution," which considers generating technologies, transportation fueled by electricity and hydrogen fuel, heating and cooling from district heating, solar hot water, and heat pumps. Following are four general chapters – on other technologies, electricity, photovoltaics and

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Rees skeptical about future without austerity

by John L. Roeder

William Rees is Professor Emeritus of Human Ecology and Ecological Economics at the University of British Columbia. His article on "Globalization and Sustainability: Conflict or Convergence" in the August 2002 issue of the *Bulletin of Science, Technology and Society* stirred a lot of discussion in the "Physics and Society" listserv of the American Association of Physics Teachers, and I covered it in our Spring 2004 issue. There Rees discussed the impact of a human life on Earth in terms of a concept he co-invented, the ecological footprint.

Rees's thesis is that the last two centuries have been anomalies in human history, during which we have used the solar energy stored in plants from all the time before, where high temperature and pressure formed it into fossil fuels. We have done this at unprecedented rates, stuffing the atmosphere with increasing quantities of carbon dioxide – and this has allowed both our population and standard of living to escalate.

He reminds readers of this thesis in two pieces he penned for *The Tyee* on 11 and 12 November 2019, beginning each one with a question. His question on 11 November is

The modern world is deeply addicted to fossil fuels and green energy is no substitute. Am I wrong?

Here he points out that the fossil fuels which furnish 84% of the world's primary energy sources have fostered urbanization, with 43 cities with populations greater than 10 million expected by 2030, mostly in Asia, and 6.7 billion urban residents comprising 68% of total population by 2050. To this he adds, "Despite rapid growth in wind and solar generation, the green energy transition is not really happening."

Rees's question on 12 November is

Human nature and our methods of governance are proving incapable of saving the world. We need to "get real" about climate science. Am I wrong?

Here he points out that 33 climate conferences and 6 major international agreements in the last 50 years have had no effect on the rising atmospheric concentration of carbon dioxide. The 2019 EIA *International Energy Outlook* foresees a 45% increase in energy required by 2050, expected to be greater than the increased availability of renewables. The Paris commitments achieve only a third of what is needed to limit the post-industrial global tem-

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Rees

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perature increase to 2°C, the goal of the UN Framework Convention on Climate Change. Rees is also concerned about permafrost melting, release of Arctic methane hydrates, and boreal forest destruction, leading to a "Hothouse Earth."

People favor the *status quo*, depend on growth and "the illusion of 'rescue-by-technology,'" Rees writes, adding that some "interpret the threat of climate chaos as an investment opportunity." Not being considered are changes that would reduce demand for energy and goods, and population; and change in lifestyles and wealth distribution. "Policy for climate disaster-avoidance seems designed to serve the capitalist growth economy and make the latter appear as the solution rather than the cause of the problem."

If we are to limit the post-industrial global temperature increase to 2°C, Rees writes, we need to halve our carbon dioxide emissions by 2030 and eliminate them altogether by 2050. To do this, he proposes his own 11-step "Green new deal," paraphrased as follows:

1. End material growth and lower our ecological footprint.
2. No exploitation of ecosystems faster than they can regenerate.
3. Recognize that a transition to green energy is difficult/impossible.
4. Assistance to facilitate sustainable lifestyles.
5. Economic disincentives to use fossil fuels/waste energy.
6. Retrain the workforce accordingly.
7. Restructure the economy to limit carbon while developing sustainable energy sources.
8. Carbon allowed only for agriculture, space heating, and interurban transportation.
9. Reduced need for interurban transportation.
10. Income/wealth redistribution.
11. Ease world population down to two to three billion.

Rees's pieces can be accessed online at <http://thetyee.ca/Analysis/2019/11/11/Climate-Crisis-Realist-Memo/> and <http://thetyee.ca/Analysis/2019/11/12/Climate-Crisis-Realist-Memo/>.

Jacobson

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solar radiation and wind energy – and the book concludes with three chapters specifically focused on its thesis: "Steps in Developing 100% All-Sector WWS and Storage Roadmaps," "Matching Electricity, Heat, Cold, and Hydrogen Demand Continuously with 100% WWS Supply, Storage, and Demand Response," and "Evolution of the 100% Movement and Policies Needed for a WWS Solution."

Jacobson said that, while the book is used for a course he teaches, he also wrote it for a general audience. During his Q&A he clarified that the "social and political barriers" he had cited are those with an interest in the current infrastructure. He addresses power plants more than vehicles because the former are designed to last longer than the latter. In the drive to eliminate carbon dioxide emissions from electricity generation, he questions whether nuclear will continue to be too expensive to be useful and eschews CCS because of the additional energy it requires. He added that his 2017 home uses no gas, heats with a heat pump, and generates 20% more electricity than it needs.

Progress Toward Zero Emissions

How on target are the world's nations to reach zero carbon dioxide emissions by 2050? *Energy Monitor* has published the information in the table to the right about the G7 nations and other nations invited to join them at their June 2021 meeting in Cornwall, UK.

To see how individual companies have targeted progress toward zero carbon dioxide emissions, see the diagram on the last page of this issue. The progress is indicated by dots on six concentric circles, the outermost representing the year 2000 and the innermost representing the year 2050, with the others at decadal intervals.

Nation	Target for 2030	Change (1990-2019)
UK	68% below 1990	Down 38.4%
Germany	55% below 1990	Down 33.3%
Italy	55% below 1990	Down 23.0%
France	55% below 1990	Down 19.3%
Japan	39% below 1990	Down 4.5%
US	35-42% below 1990	Up 3.0%
Canada	23-29% below 1990	Up 24.8%
Australia	5-10% above 1990	Up 47.6%
South Africa	78% above 1990	Up 52.9%
South Korea	81% above 1990	Up 147.0%
India	413-415% above 1990	Up 352.1%

Net Zero for Canada

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0.836 Gt CO_2 eq in 2005. Forests have sequestered 0.146 Gt CO_2 eq but 0.129 Gt CO_2 eq was emitted from harvested wood, leaving a net carbon sink of 13 Mt CO_2 eq.

As Gates does in his book, *Engineering Net Zero* lists the economic sectors in order of their greenhouse gas emissions. Because of its importance in the Canadian economy, oil and gas is listed separately from the rest of heavy industry, and it is responsible for 31% of Canada's greenhouse gas emissions. Following behind are transportation (25%), buildings (12%), heavy industry (11%), agriculture and forestry (10%), electricity (9%), and waste (2%).

To achieve net zero greenhouse gas emissions by 2050 (abbreviated as "net zero"), the following plans are in store for each of these sectors:

Oil and Gas. Although the existence of an oil and gas industry in a net zero 2050 seems to be an oxymoron, with any remaining fossil fuel use requiring a matching amount of carbon capture and sequestration (CCS), *Engineering Net Zero* nevertheless lays out a plan for a net zero oil and gas industry in 2050, yet cautions that such a plan is fraught with economic challenges that may make it unviable. This plan even goes so far as to find non-emitting energy sources to replace the fossil fuels presently used in the industry, and a subsequent report from *World Nuclear News* (on 11 June 2021) describes the *Oil Sands Pathways to Net Zero*, which is considering small modular (nuclear) reactors along with carbon capture technologies.

Transportation. Achieving net zero in the transportation sector will be based on electrification and alternative fuels like hydrogen (which comes in two "colors": green, made by electrolyzing water; and blue, made with natural gas and carbon capture). The electrification technology exists now, but the infrastructure doesn't; it could be used for passenger and light cargo vehicles, which presently emit 89.3 Mt CO_2 eq/year (48% of the emission from transportation). Ground freight, which produces 39 Mt CO_2 eq/year (21% of the emission from transportation), is less amenable to electrification but a good candidate for hydrogen fuel. Aviation, which produces 20 Mt CO_2 eq/year (11% of the emission from transportation), would require less infrastructure and vehicle modification if run on synthetic fuel made from biomass. For shipping, which produces 6 Mt CO_2 eq/year (3% of the emission from transportation), *Engineering Net Zero* recommends nuclear energy, as does Bill Gates. Moreover, *Engineering Net Zero* notes that shifting 15% of freight from truck to electrified rail could reduce 5.6 Mt CO_2 eq/year and save wear-and-tear on highways.

Buildings. In addition to improving the efficiency of energy transformations in buildings, space heating (responsible for half the energy in buildings) will be addressed by condensing heaters, various types of heat pumps, and "other advanced technologies." (p. 23) Heating water (the second greatest energy source in buildings) will be done by condensing storage water heaters and heat pump water heaters. Windows, which can account for 35% of household heat loss, will be made more efficient by inserting inert gas between the panels of double glazing, improved weather stripping, and improved locking mechanisms. Lighting will be done with compact fluorescent bulbs (CFLs) and light emitting diodes (LEDs). The Canadian government will need to mandate "more stringent building codes," (p. 24) and energy performance standards.

Heavy Industry. Regardless of maximizing recycling and minimizing materials use, the need for steel and cement manufacture will persist. Searches for "a viable low or zero carbon solution for producing those commodities" are developing a "carbon-free aluminum smelting process" which produces only aluminum and oxygen and a "cement-free, carbon-negative concrete." (p. 25) Blessed with plentiful cheap clean electricity, natural resources, and technical talent, Canada recognizes that it is well-positioned to develop new technologies that will help to attain a net zero world.

Agriculture and Forestry. Food production in Canada has doubled without increasing greenhouse gas emissions in the last 15 years, but it is noted that the mass of Mt CO_2 eq to make a kilogram of protein for beef is thrice that for cows' milk, which in turn is greater than that for pork or chicken. Also needed are reduction of nitrous oxide from fertilizers, breeding techniques to shorten the time to livestock maturity, management of manure to maximize transmission of nutrients to the soil, learning to use agricultural residue to make biomass fuels, and reforestation.

Waste. The main target here is the 26 Mt CO_2 eq/year emitted as methane from landfills, the last of which is one of the "co-benefits of waste prevention, diversion, and landfill gas capture." (p. 29)

Electricity. The present energy sources for Canadian electricity are hydro (62%), nuclear (14%), natural gas (10%), coal (6%), wind (6%), solar (1%), and bio/geothermal (1%). To reach the goal of a net zero 2050, two things must happen: 1) the fossil fuels presently used to generate electricity must be replaced by "clean" sources; 2) the total electrical energy generated must be tripled from its present 500 TWh to 1500 TWh, in order to accommodate both the projected increase in direct use and generation of green hydrogen fuel. The coal presently used to generate electricity is expected to be replaced

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Commentary

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David Fridley, was described in detail in our Fall 2017 issue. Mark Jacobson's paper was described also in our Fall 2017 issue; and his recently-issued textbook is profiled in this issue. Because renewable energy sources benefit humans most readily when transformed into electricity, these visions were based on electrifying as much human dependence on energy as possible, with only a small amount of portable fuel made from biomass. Many responded that the intermittency of solar and wind required more than hydroelectricity to meet the on-demand requirements of the electrical grid and argued that nuclear (which is *not* renewable) would also be needed to meet future energy needs without emitting carbon dioxide.

Whereas these visions of a renewable energy future were a striking advance from the feeling in the 1970s that such a future was "pie in the sky," they were still only descriptions of what *could* be done in the form of proof of principle. Meanwhile, I was still dependent on natural gas to heat my house and on gasoline to drive my car, both of which add carbon dioxide to the atmosphere. Then, in February 2021, I noticed items in my daily newspaper (the *Times of Trenton*) that these things were going to change. Some municipalities had passed ordinances disallowing gas hookups in new construction, and these buildings would be heated by electric heat pumps. And while many automobile manufacturers had marketed electric vehicles, word was coming out that some of them would be making only electric vehicles in the near future (Volvo by 2030, General Motors by 2035). The International Energy Agency would have all new buildings emission-free by 2030 and allow no fossil-fueled cars sold after 2035.

The International Energy Agency also notes that progress after 2030 will require technologies yet to be developed, and that they will require more mineral content than present technology – among the elements they cite the need for more of are lithium, graphite, nickel, and cobalt (for electric vehicles), copper (for electrification), and nickel, zirconium, and platinum (for hydrogen production and fuel cells). The need for yet-to-be-developed technologies is also recognized by Bill Gates in *How to Avoid a Climate Disaster*, which targets 2050 as the year to achieve zero carbon dioxide emissions and maps out a plan to do so. The same target has already been set by Canada, and *Engineering Net Zero* maps out their plan. (Both documents form the basis of the lead stories of this issue.) But it is important to note that both the Gates and Canadian plans include nuclear energy in the mix for zero carbon dioxide emissions. (The *UK Energy System Modelling Net Zero 2050: Nuclear Deployment Scenarios to Support Assessment of Future Fuel Cycles* report indicates that the same thing is happening in the United Kingdom.)

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by natural gas by 2030, and the natural gas plants outfitted with CCS or retrofitted to use hydrogen fuel by 2050.

Fortunately, Canada has sufficient hydroelectric reserves (154.971 GW in addition to the presently-used 80.846 GW) to triple its electricity production, but many more transmission lines must be built to access them and to incorporate the additional solar and wind-generated electricity that is needed to achieve net zero. The electrification needed for a net zero 2050 could be achieved by any one of the following or a fractional combination of any of them:

115 1100 MW hydroelectric plants
114 1000 MW nuclear reactors
380 300 MW small modular reactors
20,000 10 MW wind turbines
>400 GW solar

The expected combination is 50% (500 TWh) from hydro; between 275 TWh and 440 TWh from nuclear (from one 1000 MW reactor per year beginning in 2030 and three 300 MW small modular reactors per year beginning in 2035); 300 TWh from wind, added at a rate of 3 GW per year; and 60 TWh from solar. The energy sources thus envisioned for generating Canada's electricity in a net zero 2050 would then be hydro (43%), nuclear (24%), wind (19%), natural gas (with CCS or retrofitted for hydrogen) (8%), solar (4%), and bio/geothermal (1%).

Nations also committing to a 2050 with zero carbon dioxide emissions include France, South Korea, and Switzerland, which, along with Canada, is blessed with abundant hydroelectric energy. According to Kelsey Misbrener's article, "Environment America launches 100% renewable campaigns in 13 states," in the 8 February 2021 issue of *Solar Power World*, so do such American states as California (*before* 2050), Florida, Georgia, Massachusetts, North Carolina, and Pennsylvania. Other states with commitments to zero carbon dioxide emissions (but with no target date) include Illinois, Texas, and Wisconsin. And, according to NPR, China has committed to zero carbon dioxide emissions by 2060. Other nations and states have made various commitments to zero carbon dioxide emissions from *electricity* generation.

The upshot of all these commitments is that the world is realizing that the time has come for us to give up the fossil fuels that have made our lives convenient because the viability of our planet is more important. Next year I can speak to my students that this change is really going to happen – and tell them about the things they can expect to see in their own lifetimes.

- John L. Roeder

Gates

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farmer in Nebraska and a subsistence farmer in India, and he contemplates the increased number of asylum seekers.

Gates points out that there will be economic and health effects too, and that there are two things we can do: adapt to these effects or mitigate against them. Mitigation, to him, is the only sane alternative: "To have any hope of staving off disaster, the world's biggest emitters – the richest countries – have to get to net zero emissions by 2050," he writes (p. 35). He also points out that the richest countries are also the best positioned to do this, since they will lead the global economy in the future.

In his second chapter Gates recalls how fossil fuels were added to our energy sources by the Industrial Revolution, and that we have taken them for granted ever since. Moreover, as less developed parts of the world follow in the same energy path, the demand for fossil fuels will further increase. Some of them are used to generate electricity, and Gates points out that this is not like manufacturing, in fields as diverse as electronics and medicine, where most of the cost goes into making the first item, after which economies of mass production set in. Rather, generating electricity requires large capital investment, which must be continually used over its planned lifetime. Getting to zero greenhouse gas emissions requires new laws and policies that address the issues of climate change and a consensus that eliminating greenhouse gas emissions is as important a priority as health or education. And it also requires global cooperation.

Gates begins his third chapter by observing that getting the big picture is an important first step to learn about a problem, allowing him to determine the questions he needs answered to solve it. His big picture of the 51 billion tons of greenhouse gases annually emitted in the third chapter is to categorize them into five groups: manufacturing (accounting for 31%), electricity generation (27%), food (19%), transportation (16%), and indoor climate control (7%). He lists the energy sources used today by their energy densities – from fossil fuels and nuclear, which generate a minimum of 500 watts per square meter, to biomass, which produces less than a watt per square meter (solar does better, with a range of 5-20 watts per square meter, and wind not quite as well, at 1-2 watts per square meter). Then he defines the difference between a zero-carbon (non-greenhouse gas emitting) energy source and its fossil fuel equivalent as the Green Premium. Economics would dictate choosing the least expensive Green Premiums and funding reduction in their cost. Achieving a zero-carbon world would require that the whole world be able and willing to pay these Green Premiums.

For situations, such as making cement, which have no zero-carbon solution, Gates determines the Green Premium from the cost of capturing the carbon by Direct Air Capture, which presently costs more than $200 per ton of carbon dioxide. If this cost were reduced to $100/ton, the cost of eliminating the 51 billion tons presently emitted every year would be $5.1 trillion, which Gates notes is less than the cost of COVID-19 to the economy divided by the corresponding reduction in greenhouse gas emissions, which Gates calculates to be $2600-$3300/ton in the U.S., and more than $4400/ton in the E.U.

The next five chapters are devoted to each of Gates's categories of greenhouse gas emissions, in descending order of the amount of emission, except that he begins with electricity generation, because of the major role it will play in a world of zero greenhouse gas emissions. He begins his fourth chapter, on electricity generation, with the observation that although the first energy source for the U.S. electric power grid was hydroelectricity, its expansion was based on fossil fuels. He recognizes that replacing these fossil fuels with renewable energy sources would require transmitting solar power from the Southwest and wind power from the Great Plains, which is a more massive undertaking than shipping coal on a train or gas through a pipeline to a local power plant. "But cheap oil and expensive transmission lines aren't the bigger drivers of the electricity Green Premium," he goes on. "The main culprits are our demand for reliability, and the curse of intermittency." (p. 75)

Gates then works out the simple of example of storing a kilowatt hour of solar energy to be used at night with a $100 battery that can handle 1000 energizing cycles: 10¢/kWh, twice the original cost of the energy. He notes that renewable systems also need to take into account seasonal variation – Seattle gets twice as much sunlight on the Summer Solstice as on the Winter Solstice. Gates's Breakthrough Energy is building a computer model of all U.S. transmission lines, which shows that a coordinated regional and national approach will achieve emission reduction goals with 30% fewer renewables than independent state approaches. In order to electrify our present use of fossil fuels for transportation and home heating, we will need to increase our electric power capacity by factor of more than two, Gates notes; and this means that decarbonizing America's power grid by 2050 requires adding generation capacity of 75 gigawatts per year, more than three times the present rate of 22 GW per year.

"Changing America's entire electricity system to zero-carbon sources would raise average retail rates between 1.3 and 1.7 cents per kilowatt hour, roughly 15 percent more than what most people pay now," Gates writes (p. 72). A different methodology calculates the Green Premium for Europe to be about 20%. These areas are blessed with renewables and access to financing, he adds.

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Gates

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But Asia and Africa are not so blessed but have benefited from coal-fired plants built for them by China.

Because of financing and time constraints, Gates feels that it is unwise to attempt to decarbonize the world's energy sources by 2050 without nuclear energy, which he writes is "the only carbon-free energy source that can reliably deliver power day and night, through every season, almost anywhere on earth, that has been proven to work on a large scale." (p. 84) Without it "getting to zero-carbon electricity would cost a lot more." (p. 85) He also notes that nuclear plants are second only to natural gas in materials needed to generate a unit of electrical energy. Terra Power, which Gates founded in 2008, has a computer-modeled fully automated reactor which can be built under ground. In addition to supporting energy from nuclear fission, Gates also supports continued research in nuclear *fusion*.

Accommodating the intermittency of solar and wind energy requires that electrical energy be stored to be used when the Sun doesn't shine and the wind doesn't blow. Of the possibilities he considers, batteries are the most promising; the others are pumped hydro (pumping water to a higher reservoir when demand is low), thermal storage (storing solar energy in heated molten salt), and hydrogen (which could be made at the generation site and shipped to generate electricity in a fuel cell at the point of need). Other ways he considers to reduce carbon dioxide in the atmosphere are 1) carbon capture and storage (CCS: captures only 90% of emissions from a power plant, is expensive, and has no economic incentive); 2) direct air capture (DAC: can be done anywhere but less efficient than CCS, which has the advantage of greater concentrations near power plants); 3) using less energy; and 4) load shifting (programming electricity uses that are not time-sensitive for times of least electricity demand – *e.g.*, energizing electric vehicles, heating water).

In his fifth chapter, on manufacturing, Gates considers the manufacture of three key items: steel, cement, and plastics. To make steel, carbon is used in the form of coke to chemically reduce the iron in ore and is also added (at less than one percent) to strengthen it into steel. Producing a ton of steel produces 1.8 tons of carbon dioxide. Cement, which is combined with gravel, sand, and water to make concrete, is made from lime (calcium oxide) which is produced by decomposing limestone (calcium carbonate) with very high temperature heat, with a molecule of carbon dioxide emitted for every molecular unit of lime produced. Plastic is formed from carbon in fossil fuels, around half of which stays in the plastic, which is notorious for not decaying.

Two of these three can be manufactured without emitting carbon. Iron in ore can be chemically reduced electrolytically, as is presently done for aluminum. And plastics can be made electrically from carbon in carbon dioxide removed from the air. But the high temperature heat required to make cement must come from nuclear or fossil fuel energy, although up to 10% of the carbon dioxide generated has been injected back into the cement. If the carbon emissions from each manufacturing process are removed by carbon capture, Gates calculate the Green Premium as a percentage of manufacturing cost to be 9-15% for plastics, 16-29% for steel, and 75-140% for cement. Gates's general procedure for removing carbon dioxide emissions from manufacturing is to 1) electrify everything possible with decarbonized electricity; 2) use fewer materials more efficiently; and 3) capture whatever carbon remains.

In dealing with the greenhouse gas emissions from agriculture in his sixth chapter, Gates confronts several situations unlike those from all the other sectors of the economy that he considers. He acknowledges that Norman Borlaug developed higher-yield crops but also notes that they require large amounts of fertilizer. Although plant growth absorbs carbon dioxide, making fertilizer uses fossil fuels, which emit it. And the alternative of using biofuels instead would require growing additional plants to produce them. Gates also notes that a great deal of the energy needed to make fertilizer is associated with nitrogen. Except for legume crops, energy is required to put nitrogen into the chemical form found in ammonia. Clean electricity could meet this need and also be used to bring the fertilizer to the field, but at an added 20% cost; and there is no way to eliminate the nitrous oxide, another greenhouse gas, emitted as a consequence of the failure of plants to absorb all the nitrogen in applied fertilizer. Possible remedies include monitoring fertilizer application to avoid excess, additives to enhance nitrogen absorption by plants, and genetic modification to "recruit" the nitrogen "fixing" bacteria that are found in legume crops.

Agricultural animals present even greater greenhouse gas emission problems. Gates notes that "ruminants, like sheep, goats, deer, and camels" (p. 117) burp and fart methane, "Which cause[s] 28 times more warming per molecule than carbon dioxide over the course of a century" (p. 113); and the excrement of all animals emits nitrogen pentoxide, which per molecule has 265 times the effect of carbon dioxide. This collectively accounts for more than seven billion tons of carbon dioxide equivalent. One response is plant-based meat, but its Green Premium is 86% of present costs. An easier response is like one the advice to use less energy in chapter 4: reduce the amount of food wasted (currently more than 20%).

Seventy percent of greenhouse gas emissions from our use of the land come from agriculture; the other 30% come from deforestation. The most logical antidote is to

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plant new trees, each of which absorbs four tons of carbon dioxide in 40 years. But planting trees to offset the greenhouse gas emissions of all Americans would require half the world's landmass, at the time that we also need to increase the world's food output by 70%. Gates adds some things to consider when planting trees: 1) Would a tree have grown naturally where you plant one? 2) A tree in snow reduces albedo (reflection of sunlight, which also reduces climate warming), while a tree in the tropics releases moisture to create sunlight-reflecting clouds. 3) Would replacing agriculture with a forest cause a forest to be felled elsewhere to replace the former agricultural use?

Transportation, the topic of the seventh chapter, ranks fourth of the five categories of greenhouse gas emissions worldwide, but it ranks first in the U.S., based on gasoline (which "packs a punch" and is "cheap" (p. 131)) and related liquid fuels. We've relied on these fuels for only a minute fraction of human history, Gates notes, but we won't give them up without a substitute that's as cheap and convenient.

Cars contribute 47% of the greenhouse gas emissions from transportation, and Gates considers two alternatives to fueling them: electricity and alternative fuels. He finds that driving a Chevy Bolt costs ten cents per mile more than driving a Chevy Malibu, but this differential will decrease as gasoline prices increase and battery prices decrease. Biofuels made from specially-grown plants compete with agriculture, and even biofuels that don't compete with agriculture require greenhouse gas emissions from the energy needed to refine them. Zero-carbon electricity can separate hydrogen gas from water and react it with carbon dioxide to make hydrocarbon fuels, but the Green Premium is 106% for "advanced biofuels" and 237% for "electrofuels." The time to transition from internal combustion engines also depends on their average lifetime of 13 years.

Of the remaining vehicles that emit greenhouse gases, buses and trucks account for 30% of transportation's greenhouse gas emissions; and planes and ships account for 20%. Buses and garbage trucks, Gates points out, run short routes and can be re-energized overnight, so carbon-free electricity is a practical option for them. But with only one thirty-fifth of the energy density of gasoline, lithium ion batteries are not viable for long-haul trucks. The Green Premiums for zero-carbon fuel alternatives to diesel are about the same as those for the comparable alternatives to gasoline.

Planes and ships have the same energy requirements as long-haul trucks, and the cost of advanced biofuel and electrofuel options for them is comparable to the cost of comparable alternatives to gasoline. But because jet fuel is cheaper than gasoline, and the bunker fuel burned by ships even less expensive, their Green Premiums are greater. Gates add that nuclear energy should be explored for shipping, as it is already being used to energize naval ships.

"With transportation," Gates writes, "the zero-carbon future is basically this: Use electricity to run all the vehicles we can, and get cheap alternative fuels for the rest." (p. 147) But we should use those fuels more efficiently and only when they are needed. And electrifying transportation along with manufacturing requires scaling up zero-carbon electricity generation even more.

The final category of greenhouse gas emissions, treated in the eighth chapter, is space heating and cooling. Gates notes that 99% of space cooling is energized by electricity and that most households in the developed world are so accommodated. He also notes that less than 20% of the developing world is and that the expected increase in this percentage will increase the demand for electricity and thus warm the Earth even more. At the same time, he expects that redesigning air conditioning systems to be more efficient could reduce their energy demand by 45%.

In addition to greenhouse gas emissions associated with electricity generation to provide space cooling, Gates also cites another greenhouse gas emission associated specifically with refrigerants used. Gates calls them "F-gases," because they contain the chemical element fluorine (symbol F). Although they constitute only 3% of greenhouse gas emissions, their effect per molecule on warming is thousands of times that of a carbon dioxide molecule. Gates writes that international agreement is on track to reduce their use by 80% by 2045.

While the greenhouse gas emissions from space *cooling* come from power plants, most of them from *heating* space and water come from burning fossil fuels in home furnaces. Gates's advice for dealing with this is the same as for transportation – electrify as much as we can. Although electric space heating in the past has been eschewed because of its inefficiency (since only 40% of the energy contained in fossil fuels is transformed into electrical energy in a power plant), Gates extols the new alternative of a heat pump, which can provide both cooling and heating by pumping heat in from the outside in winter and out from the inside in summer. Moreover, for most new installations, depending on climate and the cost of electricity and natural gas, a heat pump can do so with a *negative* Green Premium, while continuing to operate oil and gas furnaces with advanced biofuels carries a Green Premium of 103% and 142%, respectively (and 234% and 425%, respectively, for electrofuels). But as the time to transition from internal combustion engines depends on their average lifetime, the changeover from

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fossil-fuel burning furnaces can't occur until they need to be replaced.

After cataloguing the five sources of greenhouse gas emissions and offering his suggestions for eliminating them, Gates turns in his ninth chapter to what we can do to live with the consequences of those already emitted. Climate change threatens the greatest harm to the world's poor, who did the least to cause it, he observes. Yet, there is hope: The Consultative Group for International Agricultural Research, a network of 15 independent research centers at which Borlaug did his groundbreaking work, has developed new crop varieties that can thrive in expected more extreme weather – *e.g.*, drought-tolerant maize and rice that can tolerate long periods under water.

Gates also advocates climate-proofing cities, mostly preparing for higher levels of water; restoring ecosystems (he is concerned about coral reefs and extols the value of mangrove trees); preparing to desalinate ocean water to insure sufficient potable water despite its energy cost and attracting public and private investment to do this (he asserts that a $1.8 trillion investment will yield $7 trillion benefits). And, should the world be headed toward a "tipping point," as would happen if the methane hydrates in the Arctic release their methane into the atmosphere, the nations of the world need to agree on geoengineering measures they would implement. "Those of us who have done the most to cause this problem should help the rest of the world survive it," Gates concludes. "We owe them that much." (p. 175)

Mindful that problem solving is aided by supportive policies, Gates "suggest[s] seven high-level [policy] goals" that nations should aim for in his tenth chapter:

1. "Mind the Investment Gap" – be sensitive to needed products that companies are unwilling to develop on their own and step in with research grant to speed the development process.
2. "Level the Playing Field" – "Reduce the Green Premium to Zero," (p. 186) by a combination of making non-carbon alternatives cheaper and fossil fuels more expensive.
3. "Overcome Nonmarket Barriers" – provide information to consumers about and facilitate the implementation of non-carbon alternatives.
4. "Stay Up to Date" – incorporate new technologies into regulations for projects that can benefit from them.
5. "Plan for a Just Transition" – make provision for the livelihood of those who will lose jobs in fossil fuels.
6. "Do the Hard Stuff Too" – such as electrical energy storage, clean fuels, fertilizer, cement, and steel as well as electric vehicles and solar/wind electricity.
7. "Work on Technology, Policy, and Markets at the Same Time" – because these three are so mutually dependent, they must evolve with each other in mind. Gates cites advanced biofuels as an example of policy which has not been matched by technology and markets, while solar and wind-generated electricity are examples benefiting from a partnership of policy, technology, and markets.

Gates homes in on his goal of emitting zero greenhouse gases by 2050 in his eleventh chapter, and to do this he insists that in the next ten years we need to implement policies to do this. Since the goal must be *elimination* of carbon emissions, measures that merely *reduce* them (such as substituting natural gas for coal) make no contribution to achieving the goal.

Gates has structured his plan in two elements – "expanding the *supply* of innovations" and "accelerating the *demand* for" them (p. 199), much as he did at Microsoft. Here he recreates a list of needed innovations already sprinkled throughout chapters 4-9. To achieve these innovations, he feels we must do the following:

1. "Quintuple clean energy and climate-related R&D over the next decade."
2. "Make bigger bets on high-risk, high-reward R&D projects." (Safer bets should be funded by the private sector.)
3. "Match R&D with our greatest needs."
4. "Work with industry from the beginning." (This will facilitate cooperation between government and industry to smooth the transition from the former to the latter in the R&D process.)

To accelerate the demand for these innovations, Gates feels we must

1. "Use procurement power." (Government purchase of innovative products enhances their use and acceptance.)
2. "Create incentives that lower costs and reduce risk." (Tax credits and guaranteed financing can enhance purchase of innovative products that are otherwise too costly at the outset.)
3. "Build the infrastructure that will get new technologies to market." (Examples are transmission lines for wind and solar, and energizing stations for electric vehicles).
4. "Change the rules so new technologies can compete."

Gates also notes that the zero-carbon responsibilities of government are related to their present level of responsibility. For local governments this means building construction and energy use, energy for public and police transportation, and waste management. For state governments it means electricity generation and transportation

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infrastructure. And for national governments it means national policies and regulations, financial incentives, R&D funding – and he adds that the policies to reach zero carbon emissions in 2050 must be in place by 2030.

Just as there are responsibilities of governments at every level, there are things all aspects of society can do to reach zero carbon emissions, and this is the topic of Gates's twelfth and final chapter. Citizens can voice their feelings to their elected representatives, get involved in local decision-making, or even run for elected office. Consumers can use their buying power just as governments can – to get electricity from renewable sources, reduce energy use, buy an electric vehicle, and eat plant-based food. Businesses can make zero-carbon decisions, adopt zero-carbon policies, and partner with government R&D.

Because there is a role to be played by both the private sector and government, Gates feels that advocates of a role for either will play a role reducing carbon emissions through their preferred channel. But he hopes that people will "spend more time and energy supporting whatever [they're] in favor of than opposing what [they're] against." (p. 226)

In an afterword titled "Climate Change and COVID-19," Gates finds parallels between climate change and COVID-19 and an interest in doing something about both problems, and he emphasizes that solving both problems requires international cooperation, paying attention to science, and meeting the needs of those who are hardest hit.

BOOK CLUB DISCUSSION QUESTIONS

After I finished reading *How to Avoid a Climate Disaster*, I had the opportunity to run a six-session book club for a group of seniors and chose this as the book.

To help provide some focus for the students in their reading, I formulated a set of discussion questions, which then formed the basis for our sessions together.

If you are interested in using *How to Avoid a Climate Disaster* for a book club or discussion group, I'd be happy to share my discussion questions with you. Just send a email request to JLRoeder@aol.com.

- John L. Roeder

Heating with heat pumps

by John L. Roeder

Until I read the documents described on the front page of this issue, heat pumps had been the exception rather than the rule as a way to heat buildings. Those which I had known of all were connected to extensive underground pipe systems, through which refrigerant could flow and absorb underground thermal energy to be transferred to the building above ground. The more common method of which I was aware to heat with electrical energy was to transform electrical energy from a power plant to thermal energy in a house with electric resistance, a process limited in its efficiency by the efficiency with which the heat source creating the steam at the power plant can spin a turbogenerator. This is typically only 40%, so only 40% of the thermal energy produced at the power plant would heat the building electrically, whereas burning natural gas directly in the building's furnace could heat the building with almost 100% efficiency.

Although Gates refers to heat pumps somewhat generically, *Engineering Net Zero* distinguishes between air exchange heat pumps, which are basically air conditioners run in reverse (and can be run as air conditioners as well), and ground exchange heat pumps, which are the ones connected to the system of underground pipes. In short, air exchange heat pumps exchange thermal energy between the building and the outside air, and ground exchange heat pumps exchange thermal energy between the building and the ground. Ground exchange heat pumps are more expensive because they require the underground system of pipes described above. But they would also cost less to operate, because the temperature below ground remains constant at the average above ground temperature throughout the year, and a ground exchange heat pump would get thermal energy from a warmer source than outside air in winter and transfer it to a cooler reservoir than outside air in summer.

Heat pumps are rated by their coefficient of performance, which is the ratio of the thermal energy exchanged to the work done by the pump to exchange it. This would clearly be greater for a ground exchange heat pump, and this difference between ground exchange and air exchange pumps could be especially significant in the colder climate of Canada. If the coefficient of performance dips below 1, it would be more efficient to heat the building by transforming electrical energy from a power plant through electrical resistances in the building.

An Internet search shows that the first heat pump was made by Peter von Rittinger – back in 1855-1857. But it wasn't until the 1970s, the decade of the Arab Oil Embargo, that they became popular to any degree.

(*Author's Note*: I am grateful to Collin McCullough of Princeton Air Conditioning for consultation.)

Please Reuse Me!

by Bernice Hauser
Primary Education Correspondent

"Oh… Alec, please don't discard the wrapper that holds the mandarins," I exclaimed to my grandson as he unpacked the groceries purchased for me during this pandemic. "Why save this plastic mesh wrapper?" he asked. "WHY NOT," I posited. I then explained that I was using this item as the basis of my new article for the Clearinghouse *Newsletter.*

Its purpose is how to reuse and recycle everyday items in new and imaginative ways, introducing young children to such new vocabulary as plastic, mesh, senior citizens, masks, costumes, mandarin oranges, packaging, and wrappers. You will need the following materials: wrappers from the mandarins, scissors, Scotch tape, cardboard, ribbon, cord, paper clips, huge bobby pins, a discarded window shade roller (make sure ends are not sharp), rocks, pail or empty coffee containers, and a rolling pin. Please rinse or spray or wash the mesh wrapper before using it. I rinsed it in Palmolive dishwasher liquid soap.

As you may surmise from my other articles written for the Clearinghouse *Newsletter*, I am a firm believer in soliciting children's impressions and suggestions and queries before enforcing any rigorous procedure for them to follow. Borrowing my neighbor's four year old son, Weldon, for an afternoon play date, I laid out several mandarin wrappers on a table.

Weldon examined these wrappers, asked me where I had obtained them and why were they set before us on this table. "Do you think we can pretend that we have discovered a valuable treasure – do you think that we can invent or discover new ways to use these items?" I asked.

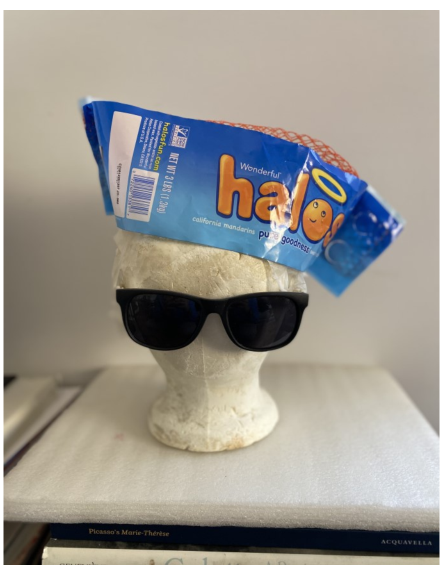

Fig. 1. King of the mandarins.

Weldon has a great comic sense so it was no surprise to me when he immediately placed one mesh wrapper on his head and announced that he was now the KING of all the Mandarins. (Fig. 1) He then lowered the wrapper and placed it on his face, saying that it was now a mask that had magic powers – he was now invisible to me and anyone else in the room. (Fig. 2)

Ah — the imagination of four-year-olds.

Knowing that his pod at nursery school holds on to a rope when they set out for recess in Central Park, I asked him if the wrappers were stapled together, did he think he and his classmates could use this line instead of the rope. He said maybe – but his teachers would have to approve the change. He added that he liked the "feel" of the rope more than the "feel of the plastic orange mesh. I appreciated his honesty.

Upon his leaving my apartment, I gave him his own wrapper and some mandarins as a reward for assisting me with my article. Several days later, I met him in the lobby of our apartment building. I asked him how things were going. He said OK, and then added that he put the wrapper on the rug in the hallway of their apartment and that his baby brother tried to roll a ball into it.

A lightbulb went off! This wrapper would make a suitable basketball hoop. Searching through my own apartment, I located a discarded window shade roller, taped the wrapper into a suitable basketball hoop, attached it to the roller and set it up in a pail that was grounded with some rocks from Central Park. I then invited Weldon for a test run. It proved workable and suitable for indoor play during these trying days. (Fig. 3)

An experiment that *did not pan out* involved senior citizens. I saved several wrappers, flattened them out, stapled them onto a stiff board and left them at a nearby assisted living facility to be used for a weaving activity. I enclosed a package of giant bobby pins and thin colored ribbon that would have to be attached to the bobby pin. The supervisor said he would let me know how the project went.

Several days I heard the verdict. The seniors, many of whom have diminished dexterity and eyesight found the holes of this mesh bag much too small for them to

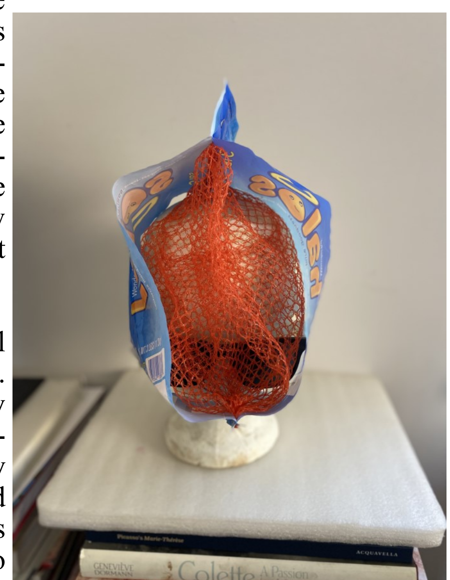
Fig. 2. A HALO mask.

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Please Reuse Me!

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enjoy the activity. But I was thanked profusely as he and management at were now planning to add a *weaving* activity to their daily activities program. This activity was my humble attempt to use discarded materials in a new and creative way and help to diminish the waste that is contributing to many of our climate problems today. Humility ruled the day, though.

A few days later, I met Weldon's mother in the lobby of our apartment building, and she informed me that she and Weldon had created a pretend sled/carrier for all his stuffed animals, placing all the stuffed animals into each of the attached wrappers and then taking them for a ride throughout the apt. I myself was experimenting by taking the blue advertising wrapper off the mesh, and then folding the mesh piece into different formations suitable for a hat; I might even try it out as a veil attachment. Hmm . . . I wonder if the mesh can be dyed a different color!

Weldon scratched his head and then uttered an Aha: "We just started to weave in our nursery school – in, over, and out . . . . He took a wrapper, requested my help in flattening it out and then he stapled it to a cardboard board. Looking at the available materials, he selected a huge paper clip which he asked me to undo, then taped a ribbon around it and began to weave it into the mesh pattern in front of him, This proved to be a daunting task for his little fingers and he soon got very frustrated. I then recalled how elemental his weaving board was at school, and the safety of using this long steel clip unnerved me no end.

"Hmm . . . let's leave this project for now, okay? Now close your eyes, open them when I say 'five.' Here's another mesh wrapper – any other use for this wrapper? Think of Halloween or the games you play."

"Well, at recess on our school deck, we play miniature field hockey with masks on our faces. Maybe we can pretend this is a face mask to use when you engage in some play games in your own home." Bravo!

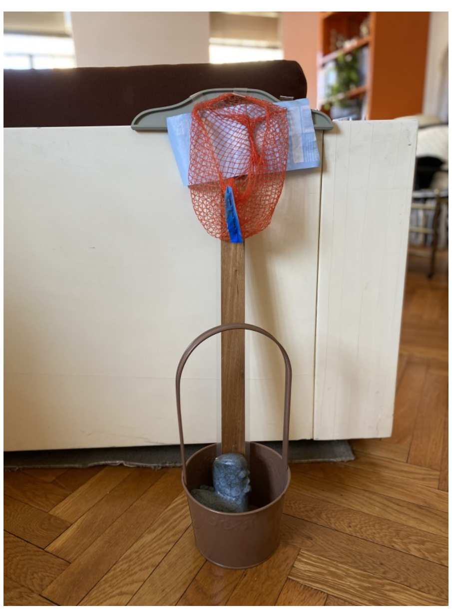

Fig. 3. A HALO basketball hoop.

Rayner-Canham relates chemistry to lives of Inuits

On 7 May 2021 the Physics and Chemistry Teachers Clubs of New York were treated to a presentation by Geoff Rayner-Canham on "Seeing Chemistry through the Lens of Inuit Life and Culture." In doing so he revealed his philosophy of bringing chemistry to indigenous cultures of Nunavut and of Newfoundland and Labrador, where he is a Chemistry and Environmental Science Professor at the Grenfell Campus of Memorial University of Newfoundland & Labrador. He has been bringing his "Chemistry is Everywhere!" outreach to these cultures since 2002, assisted by young women excelling in their chemistry and environmental science studies with him at the Grenfell Campus, also showing the importance of women in science. The most recent of these assistants has been Chaim Christiana Andersen. She is an Inuk living in the far-north community of Nain, Labrador (part of the autonomous Inuit region of Nunatsiavut).

Chemistry is traditionally taught in terms of moles, Rayner-Canham said, but this is not the way to reach the indigenous cultures of Northern Canada. But they have shown great enthusiasm for chemistry demonstrations – and have asked questions about such things as Kevlar thread, aerogel, and snow insulation, things that could play a practical role in their lives.

It was an invitation to present at an Aboriginal Youth Conference in 2015, which caused Rayner-Canham to start thinking of the chemistry concepts involved in indigenous life. It was the insights of Andersen which provided the ideas, then Rayner-Canham researched the underlying chemistry, and finally Andersen contextualized the chemistry. In the presentation on 7 May, Rayner-Canham shared with us some aspects of Inuit life and how chemistry principles were involved:

1) Snow and air, which motivated discussion of kinetic theory and phases of matter
2) Sea ice, which motivated consideration of solid and liquid phases and hydrogen bonding
3) The "grasshopper effect," a form of global distillation by which toxic materials emitted from manufacturing in temperate regions leaped poleward through the atmosphere
4) Minerals, a basis for learning about crystal structure
5) Metals and metallic bonding
6) Seal livers, which are eaten raw as a source of vitamins, which motivate learning about intermolecular forces
7) Summer berries, which also serve as sources of vitamin C (and are preserved in seal oil for winter consumption)

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Govindarajoo applies chemistry to artistry

Chemistry Professor Geeta Govindarajoo of Rutgers University applied what is known about intermolecular forces to the world of artistic painting in a Science on Saturday lecture on 23 January 2021 titled "Chemistry and Art: Like Dissolves Like – How Solubility Influences Creating and Restoring Art, Forgery and Telling a Good Story." She structured her talk around what is known about three types of intermolecular forces – London, dipole, and hydrogen bond, in order of increasing strength. London forces result from fluctuations in electron clouds, she observed, likening this to "touching fingers" in interactions between humans. The stronger dipole force results from permanent electric polarity in molecules, corresponding to humans holding hands. The anomalously strong hydrogen bond exists only between a hydrogen atom of one molecule and a fluorine, oxygen, or nitrogen atom of another and corresponds to humans linking arms.

Govindarajoo went on to explain that there are four main components of paint: 1) pigment (which can be organic or inorganic), 2) binder (to glue pigment particles to each other and to the surface being painted), 3) liquid (a solvent which allows the paint to spread), and 4) additives. Dissolving requires inserting solvent molecules between solute molecules and forming a new regime of intermolecular forces, she added. But after the liquid allows the paint to spread, it must evaporate, so the intermolecular forces between the liquid and other components must be easily broken.

Govindarajoo focused on two types of paint – oil and water. For oil paint the binder is linseed oil, a triglyceride most of whose atoms are carbon and hydrogen. This means that linseed oil interacts via London forces, and the liquid should act via the same type of force, a requirement met by turpentine. For water paint the binder is gum Arabic, made up of polysaccharides (complex sugars) and glycoproteins (amino acids plus sugars). This works because sugars are soluble in water, because their oxygen and hydrogen atoms can form hydrogen bonds.

Govindarajoo showed some videos to illustrate some examples. The first one showed an artist named Suminagashi who dropped drops of oil-based ink onto water treated with a surfactant (which has one end hydrophobic and the other hydrophilic) to make a series of concentric rings on the water as the drops of ink created ripples upon falling into it. Then the artist added yellow blobs of linseed oil (which floated on the water) and black-dyed isopropanol, which attracts both water and linseed oil). Finally a print was made by placing paper onto the water's surface to make a print, then lifting it up and letting it dry.

A second example came from a scene in *The Thomas Crown Affair* in which an explosion followed by a fire at the Metropolitan Museum of Art triggered the covering of paintings before water would be sprayed by the sprinkler system. But the jamming of one system allowed one painting to be sprayed and water color painted over oils washed away. Govindarajoo stated that this example was circumspect, since water colors could not bind to oil paints underneath because they would have a shorter drying time and would cause the underlying oil paint to crack. On the other hand, because water colors dry quickly and are absorbed into the paper, oil paints can be applied over them.

Govindarajoo then turned toward varnishes, which provide a thin protective layer between oil paint and the atmosphere. A varnish, she said, must 1) be transparent and colorless, 2) form a good bond with dried oil paint, 3) be removable without affecting the oil paint, and 4) be protective. Varnishes, she continued, are traditionally made of drying oil, resin, and solvent. After they are applied, they harden after the solvent evaporates through chemical reactions between the oils and atmospheric oxygen and reactions among varnish components. Reaction of varnish with atmospheric oxygen makes its hardened structure more polar.

What is used to remove varnish depends on the time since it has been applied. Removing recently-applied varnish calls for turpentine, which contains terpene, and triterpene is the backbone of dammar varnishes. But removing a hardened varnish calls for a polar solvent like a ketone. Alcohol is even more polar, and it can hydrogen bond, Govindarajoo noted. Varnishes are removed and replaced when they turn yellow. Their "lifetimes" are typically 50 years. Because oil paints typically take at least 25 years to harden against exposure to ketones like acetone, if applying acetone to clean the varnish from a painting believed to be old dissolves the paint, one can conclude that the painting is actually of more recent origin. In all cases, Govindarajoo pointed out, removing varnish is a gentle process, done with Q-tips.

Because the age of a painting can be estimated from the varnish covering it and antique varnish fluoresces green under exposure to ultraviolet light, authenticators carry portable ultraviolet light sources with them. However, Govindarajoo observed that those seeking to pass off a recent reproduction as an ancient original have discovered that mixing some recovered antique varnish with modern synthetic varnish causes it to fluoresce like antique varnish.

For her final example Govindarajoo considered the cleaning of the Sistene Chapel, in which Michelangelo employed two techniques: *buon frasco* (pigment added to wet plaster), from which the color is hard to remove unless it chips off, and *a secco* (pigment added to dry plaster), which is easily removed. Govindarajoo showed illustrations of how the cleaning eliminated some details added after the plaster dried.

Ruben presents perceptions of science

With an undergraduate degree from Princeton University and a Ph.D. from Johns Hopkins, Adam Ruben is a writer, comedian, and molecular biologist. As a graduate student, he was allowed to teach his own course and decided to teach one patterned after the course in "Biotechnology and its Impact on Public Policy" that he had taken from Lee Silver as an undergraduate at Princeton. This course, in turn, would provide much of the material for his talk on "Public Perception of Science Lessons from a Dead Sheep" at the Science on Saturday series on 6 February 2021.

His first lesson on the public perception of science came from hearing on NPR news of the completion of the Human Genome Project, followed by a caller concerned that this would allow people to be programmed. Programming people isn't science, he observed – it's science fiction right now. He conceded that skepticism is important in science, but pointed out that skepticism about a misperception of science is the "wrong conversation."

Ruben's second lesson on the public perception of science came from the Coalition to Ban Dihydrogen Monoxide (DHMO), which he traced back to the April Fool's edition of the *Durand Express* (MI) in 1983 but which has been resurrected many times since. DHMO, also known as hydroxyl acid, is listed, among other things, as causing death by accidental inhalation, causing tissue damage from prolonged exposure to its solid form, aiding global warming as a greenhouse gas, accelerating corrosion and rusting of metals, contributing to the erosion of soil, and being present in every stream, lake, and reservoir. After Ruben presents this information to students, he asks them whether DHMO should be allowed, regulated, or banned?

For his third lesson on the public perception of science, he lists three means of human reproduction: 1) IVF (in-vitro fertilization), 2) cloning technology, and 3) a woman carrying to term an embryo containing genetic material obtained entirely from one of her own cells. After eliciting reaction about these three reproductive methods, he points out that cloning results from transplanting DNA from a cell into a denucleated fertilized egg, so that #2 and #3 are the same.

Ruben went on to note that a clone is no more a "copy" than identical twins are "copies" of each other – they are only *genetic* copies. To illustrate, he showed pictures of a cat named "Cc," which had been cloned from another cat named Rainbow. The two cats did not look alike – conditions in the womb have an influence, Ruben said.

He displayed the article in *Nature* describing the birth of Dolly, the cloned sheep, and noted that it used the term "somatic cell nuclear transfer," not "cloning." But reaction in the press *did*, and *USA Today* wondered whether a clone murdering the organism from which it was cloned would be a suicide or a homicide. Similar press reaction was elicited when scientists were able to use frozen cells from the gastric brooding frog, which went extinct in the 1980s, to bring it back in 2013.

A further lesson on the public perception of science came from a movement to require "mandatory labels on foods containing DNA." Ruben reported that when he shared this with students, one responded that he'd be more concerned about foods that *didn't* contain DNA.

In addition to public perceptions of science, Ruben also addressed perceptions of *scientists*. He began by showing the results of Googling "scientists" and asking for images. Most of them were caricatures of old white men holding test tubes. He also showed the results that showed up when he Googled "why are scientists," "scientists are so," and "do scientists." Examples from D. W. Chambers's "Draw-a-Scientist" test looked much like the Google images, and Ruben observed that many included "keep out" signs, suggesting that "science is not for you." Yet he was encouraged by the results of pictures students drew of scientists before and after a visit to Fermilab, three of which he displayed. The "scientists" drawn before the visit wore the typical white coat, but those drawn afterward didn't – and two of them were women.

Ruben's closing thought: when you hear about a new result from science, your first reaction should not be one of praise or deprecation; it should be to find out more about it!

Rayner-Canham

(continued from page 13)

8) Arctic char, now eaten by Inuit with soy sauce, which provide fatty acids and niacin (vitamin B_3)
9) Health remedies, such as Labrador tea (from the rhododendron family), which contains germacrone; and dwarf willow, which contains salicylic acid
10) Hides and bones, which are natural polymers and composite materials.

The program was organized by Chemistry Teachers Club member Myra Hauben, who had spent her professional career teaching chemistry at the College of Staten Island. She began a similar outreach program in Cambodia in 2003. Rayner-Canham has continued to encourage Hauben to share her work in Cambodia (in writing and at conferences). Hauben also invited many of the Cambodians who have been assistants in her own outreach programs to this presentation.

RECOMMENDED SCIENCE AND SOCIETY EDUCATIONAL RESOURCES

1. Tapio Schneider, Nadir Jeevanjee, and Robert Socolow, “Accelerating progress in climate science,” *Phys. Today*, **74**(6), 44-51 (Jun 21).

This article presents a guided tour through the issues confronted in constructing a model of Earth’s climate, where the challenge is “to coarse-grain the known microscale laws into macroscale models.” Among the data needed to be incorporated are information about “clouds and the turbulence that sustains them,” the “often stably stratified polar boundary layer,” and “Earth’s land biosphere,” which “removes about 30% of the human CO_2 emissions from the atmosphere.” The scale of these phenomena is far less than the 50 km resolution of today’s global climate models, and “resolving just the meter-scale turbulence in low clouds globally would require about a factor of 10^{11} increase in computer performance.” The authors of this article write that “The net effect is that clouds cool Earth by 5^{o}C.” Yet, if their scale is below that of model sensitivity, the model cannot be expected to account for their effects in its predictions.

2. Toni Feder, “Should solar geoengineering be part of how humanity counters climate change?” *Phys. Today*, **74**(6), 22-26 (Jun 21).

The National Academies of Sciences, Engineering, and Medicine have issued a report, *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance*, which considers three measures humanity can do to stave off effects of climate change if they are needed: stratospheric aerosol injection, marine-cloud brightening, and cirrus-cloud thinning.

Aerosol injection already occurs when volcanic eruptions spew sulfur dioxide, and the cooling effects of these eruptions are well known. This article states that “industrial pollution includes about 100 megatons of SO_2 a year,” and the 1991 eruption of Mount Pinatubo added 15 more. Stratospheric injection of 10 megatons of sulfur dioxide per year would reflect about 1% of sunlight. But when sulfur dioxide oxidizes to sulfate, it destroys stratospheric ozone and heats the stratosphere.

Marine-cloud brightening “occurs when vessels spew pollution and form so-called ship tracks,” but it lasts only a “day or two.”

Whereas stratospheric aerosol injection and marine-cloud brightening both reduce the amount of sunlight incident on Earth, cirrus-cloud thinning would reduce the amount of infrared radiation emitted by Earth that is absorbed by the atmosphere and reradiated back to Earth. One environmental scientist is quoted as saying, “If you got rid of all cirrus clouds, you could negate the warming from doubling CO_2.”

But any geoengineering measure to respond to climate change would be like medicine to treat a chronic disease. Once started, it would have to be maintained.

3. David Kramer, “The cost of solar energy production has plunged, but it needs to fall further,” *Phys. Today*, **74**(6), 27-29 (Jun 21).

According to this article, “solar will need to supply 30-50% of total US power needs in a zero-carbon electricity system,” but in 2020 it provided only 2.3%. Although “PVs are the cheapest electricity source in parts of the Sun Belt when the Sun is shining,” it is in competition with natural gas, “The lowest-cost source of non-intermittent power.” Developments such as larger and thinner crystalline silicon wafers, which account “for 80% of the US PV market,” have more than halved the cost of photovoltaic electricity since 2010.

4. Stefan Van der Stigchel, “Dangers of Divided Attention,” *Am. Sci.*, **109**(1), 46-53 (Jan-Feb 21).

The thesis of this article is that “Our brain is not capable of taking on two tasks at the same time when both require the use of the working memory.” What people think of as “multitasking” is really oscillation of the attention of our brains between two tasks, and there is a penalty to be paid for it, either in efficient use of time or accuracy of results. We are most productive on a task when we can stay focused on it, and this focus can be disturbed by external interruptions or our own lack of concentration. There is also a correlation between ease of distraction and use of social media. Music in the background has been found to extend a period of concentration if we don’t devote our working memory to listen to it attentively. It also keeps out other sounds that could be interruptive; and, if our concentration does flag, it can give us some pleasurable moments to rebuild our concentration to get back to work.

5. Emily Mortola and Manyuan Long, “Turning Junk Into Us: How Genes Are Born,” *Am. Sci.*, **109**(3), 174-181 (May-Jun 21).

After describing that a gene begins with an *opening reading frame* and “ends with one of three possible finish line signals” and “is both transcribed and translated,” this article turns to the part of the genome that doesn’t meet these requirements and is therefore classified as “junk” DNA. Research studies on rice have indicated the evolution of *de novo* genes from this “junk.”

REVIEWS OF SCIENCE AND SOCIETY EDUCATIONAL RESOURCES

Joshua S. Goldstein and Steffan A. Qvist, *A Bright Future: How Some Countries Have Solved Climate Change and the Rest Can Follow* (Hachette, New York, 2020). 276 pp. $16.99. ISBN 978-1-5417-2411-2 (paperback).

As a Climate Reality Project leader and mentor, I seek out books about the climate crisis. When I began reading *A Bright Future*, I quickly realized that the authors are advocates for nuclear power as a primary means of addressing the climate crisis.

In the summer of 1976, I completed a nuclear science workshop hosted by the Pennsylvania State University nuclear science department. The workshop facilitators organized an excellent learning experience, and I came away believing that commercial nuclear power was the best solution to the energy challenges we faced at that time. Three years later the Three Mile Island nuclear plant accident occurred, and in 1986 the Chernobyl disaster transpired in Ukraine. I soon became anxious about the safety and reliability of commercial nuclear power.

During the first decade of the twenty first century advocates for nuclear power stepped forward, promoting it as an important mitigation strategy to deal with the climate crisis. Then the Fukushima nuclear plant disaster occurred, and the public became more anxious about commercial nuclear power. The book by Goldstein and Qvist relieved my discomfort regarding expansion of nuclear power generation as a solution to the climate crisis. In the foreword, Harvard Professor of Psychology Steven Pinker describes the book as "climate change for grown-ups."

Goldstein and Qvist begin with a description of the effects of the climate crisis we currently experience. Their approach is that we need what they describe as nuables – a combination of nuclear power generation and renewables. A histogram is included on page 55, indicating kilowatt hours added per year of nuclear power, and of wind and solar combined, for a number of countries. The comparison is informative. The conclusion of the authors is that striving to convert to 100 % renewables is not the solution to the climate crisis.

Next, for power generation, the authors analyze replacing coal and oil with methane in the form of natural gas. They indicate that despite the reduction in carbon dioxide produced using methane, it still results in a massive amount of greenhouse gas added to our atmosphere. And there are other problems that result from converting to methane as a fuel, including the fact that when released into our atmosphere, methane has more than eighty times the warming effect of carbon dioxide.

In the chapter titled "Safest Energy Ever," facts about the safe performance of nuclear power plants are presented. The analysis begins with the 2011 Fukushima Daiichi power plant accident in Japan. The authors indicate that more than 1,600 people died as a result of the accident, and none of those people died from exposure to radiation. Fear of nuclear energy, causing people and their leaders to react inappropriately, resulted in those deaths. Following the Fukushima natural disaster, Japan and Germany chose to close their nuclear power plants, replacing the power those plants generated with fossil fuel plants. Goldstein and Qvist indicate that more than 10,000 people in those two countries have died as a result of the toxic gases dumped into our atmosphere by those fossil fuel plants.

The accidents at the Three Mile Island nuclear plant in Pennsylvania, and in Chernobyl, Ukraine, are analyzed next. The authors write, "[The Three Mile Island accident] was expensive but harmless." "The containment structure [of the plant] prevented radiation from affecting the surroundings."

The accident at the Chernobyl plant was caused in part by the lack of a containment structure as part of the plant, which resulted in a large radiation release into the environment. The Soviet leadership tried to cover up what had occurred, resulting in additional radiation exposure to the local population. Later, an exclusion zone was established around the damaged plant. The authors write "Several decades later, scientists studying the exclusion zone are seeing one of the healthiest ecosystems in Europe."

Comparing those accidents with the operation of nuclear power generating plants in the U.S., the authors indicate that while producing one fifth of our electric power, no one has ever been killed. An interesting histogram is found on page ninety-six, comparing deaths per terawatt-hour from power generated by coal plants, and from nuclear plants. Information about fossil fuel related disasters can be found at <https://www.americanprogress.org/issues/green/news/2011/04/19/9463/fossil-fuels-a-legacy-of-disaster/>.

The authors next provide a comparison of regulation of the nuclear power industry with other industries. They conclude, "Nuclear power might be easier to sell to a frightened public if there were more accidents. Then it would look more like commercial aviation – yeah, people sometimes die, but it's way safer than the alternative."

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REVIEWS

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Goldstein and Qvist then analyze the challenge presented by radioactive waste from nuclear power plants. They present a comparison of the waste produced in the lifetime of a single U.S. citizen – 136,000 pounds of waste for coal, *two* pounds of waste for a nuclear plant, with just a trace being long-lived radioactive waste. Information about the success of dry cask storage of nuclear waste is presented. Later in the book, Goldstein and Qvist write of fossil fuel power plants using our atmosphere as a sewer, dumping enormous amounts of toxic waste into the air we breathe. They write, "Nuclear waste storage is not an urgent problem the way climate change is an urgent problem."

Another issue regarding nuclear power generation that must be addressed is nuclear proliferation. Goldstein and Qvist site the work of an expert on nuclear fuel and proliferation, Daniel Poneman, who proposed an Assured Nuclear Fuel Services Initiative. This would guarantee reactor fuel prices to countries that commit to not work to enrich or reprocess nuclear power plant fuel. Enrichment of uranium is an issue for me, as few people can explain what is done to uranium to enrich it. This is because few people understand that enrichment involves the isotopes of uranium, or what isotopes are. That situation is a reflection of how little people understand about nuclear power generation.

In a chapter titled "Keep What We've Got," the authors cite statistics about the effects of closing nuclear power plants in the U.S. This includes information about the Shoreham nuclear power plant in Long Island, which, due to political opposition, was not opened when it was completed in 1989. The power that would have been generated by the plant was replaced by fossil fueled plants, which have dumped 80 million tons of carbon dioxide into our atmosphere. A histogram on page 153 indicates that similar policies are being followed by other countries.

The nuclear reactors in use today are second-generation plants. Goldstein and Qvist analyze the development of third and fourth-generation plants, some of which are currently in operation, with more under construction. Information is provided about the main manufacturers of third-generation nuclear power plants in the U.S., Westinghouse, and General Electric, as well as those in other countries. Extensive material is included about the development of fourth-generation nuclear plants. This includes traveling wave reactors, molten salt reactors, Small Modular Reactors, thorium reactors, and, something that surprised me, offshore nuclear power plants. The authors site the political advantage of fourth generation reactors as they have the potential for cheaper power. They indicate that there is strong support in the U.S. Congress for fourth-generation plant research and development. The authors also touch on fusion reactor research, and geoengineering proposals to deal with the climate crisis.

The climate crisis is a global challenge, and the authors indicate that China, Russia, and India face great constraints in dealing with the challenge. A histogram on page 176 provides the number of nuclear power reactors under construction in 2018 in fifteen countries. China, India, and Russia lead the pack. Three keys to low-cost nuclear power are identified: standardized design applied repeatedly, government support, and building multiple reactors at each site.

Goldstein and Qvist then proceed to analyze pricing carbon pollution. They begin by identifying Sweden as having the highest price for carbon pollution, called a carbon tax, or fee. Next, they briefly present information about waste disposal systems already taxed, such as sewers, landfills, and automobile emission inspections. They take the stand that people must pay the cost of their actions, and that a carbon tax is like a sewer tax. Our atmosphere should not be used freely as a sewer for carbon dioxide. This topic is discussed extensively in the book. A carbon tax/fee can provide funding needed to meet the challenges of the climate crisis.

In a chapter titled "Act Globally," the effort of the Canadian province of Ontario is cited. From 1976 to 1993 sixteen nuclear power plants were constructed there, and in 2008 Ontario closed its last coal-operated power plant. In this chapter it is also noted that "Groups most actively opposing nuclear power are those most vocal about climate change."

In concluding, the authors write, "The examples of countries that have harnessed nuclear power along with renewables proves that we can decarbonize and prosper economically and socially. Saving the planet is not a burden to share, but a chance to reinvent ourselves for the better."

In the last two years, as a Climate Reality Project Leader, in an effort to increase people's awareness, I have made many climate crisis presentations to teachers and students. The evidence that addressing the climate crisis is urgent seems overwhelming. This book has reinforced my feeling of urgency, and the need to address the crisis using nuclear power.

\- Frank Lock

(*Editor's Note*: Frank Lock is a retired high school physics teacher and Climate Reality Project Leader/Mentor. Please read the reviewer's article on the next page about the Climate Reality Project.)

Clearinghouse Update

From time to time we update our readers on situations which have been described in our *Newsletter*.

Rising Above the Gathering Storm Redux

Our Fall 2005 issue headlined publication of the Congressionally-requested report from the National Academies of Science, Engineering, and Medicine, *Rising Above the Gathering Storm*, to chart a path to improve science education in the United States in order to insure a continuous high-quality scientific and technological workforce. Five years later the National Academies asked the authors of *Rising Above the Gathering Storm* to revisit their original report, and their follow-up report, *Rising Above the Gathering Storm Revisited*, carried the subtitle, *Rapidly Approaching Category 5*. This was headlined in our Fall 2010 issue.

Adam Jaffe's review of Michael S. Teitelbaum's *Falling Behind? Boom, Bust and the Global Race for Scientific Talent* (Princeton, Princeton, 2014) in the 2 May 2014 issue of *Science* indicates Teitelbaum's acknowledgment that "the average scores of American K-12 students on internationally compared math-science tests are mediocre to poor" but notes that "Teitelbaum shows that the difference in average scores is . . . due primarily to the poor performance of the lower tail of the distribution." Jaffe's review goes on to say that this "has almost nothing to do with the supply of scientists and engineers, who come overwhelmingly from the upper tail of the distribution."

Regarding the strength of the scientific and technological workforce, Teitelbaum argues that funding for scientific and technological research should be guided by the amount needed to sustain the employment by the scientists and engineers in our society.

Are Quasicrystals formed by Nuclear Tests?

Our Winter/Spring 2015 issue contained an account by Paul Steinhardt of netting a quasicrystal from his trip to Chukotka, the northern part of Kamchatka. In that account Steinhardt cited a Luca Bindi from Firenze who had a sample of khatyrkite from the Karyak Mountains in Karisk (Russia). The Sigma Xi *Smart Brief* from 19 May 2021 contains an article from *Inverse* describing the discovery of a quasicrystal by the same Luca Bindi at the Trinity site in New Mexico, where the first nuclear explosion was conducted in 1945.

According to the article, "The intense heat and pressure emanating off the bomb" was able "to fuse sand and metal infrastructure around it into a green, glass-like material dubbed 'trinitite.'" The article calls the quasicrystal identified by Bindi a "blood-red cousin of trinitite." Bindi is quoted as saying that "The only known examples of older quasicrystals are the naturally formed quasicrystals discovered in the Khatyrka meteorite that date back at least hundreds of millions of years and perhaps to the beginning of the Solar System," which dovetails with Steinhardt's account.

The Climate Reality Project

by Frank Lock

In March 2019, I spent twenty-four hours over three days training to become a Climate Reality Project Leader. In that capacity I have made about forty presentations to students, teachers, and adults. In the spring of 2021, I applied and was accepted to mentor ten new Project Leaders. Working with them, I completed fifteen hours of online training.

The mission of the Climate Reality Project is to catalyze a global solution to the climate crisis by making urgent action a necessity across every sector of society.

There are approximately 31,000 Climate Reality Leaders worldwide. Climate Reality Project Leader trainings are held throughout the year, and information about training sessions can be found at the project's website, <https://www.climaterealityproject.org>.

Climate Reality Leaders hail from 154 countries. Each year, a project titled 24 Hours of Reality is hosted by leaders worldwide, who make presentations over the course of one day around the planet. The Climate Reality Project is a well-organized effort to address the climate crisis.

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