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Nuclear Power:
Totally Unqualified to Combat Climate Change

An Open Letter from the World Business Academy to leading climatologist Dr. James Hansen regarding his advocacy of nuclear power as a solution to global warming.

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Re: Nuclear Power as an Agent in Combatting Climate Change

Dear Professor Hansen:

I am the founder and President of the World Business Academy,[1] a non-profit business think tank established in 1987 with a mission to (i) explore the role and responsibility of business in relation to critical moral, environmental, and social issues of our day; (ii) inspire the business community to assume responsibility for the whole of society; and (iii) assist those in business who share our values to take greater responsibility for positive social outcomes from business initiatives. The Academy's projects and numerous publications take on today's challenges including environmental degradation; the shift away from dirty energy and toward clean, renewable energy; and the existential threat posed by climate change. In fact, the Academy has had an active Energy Task Force working continuously on these issues since 1997. Academy Fellows, representing some of the best and brightest men and women shaping today's global landscape, have analyzed, reported and predicted the transforming paradigm shifts in business and society.[2]

My colleagues and I at the World Business Academy have followed your climate activism for many years and your on-going campaign to restrain the coal and oil industries with great interest. Your research, congressional testimony, and activism to address climate change has brought this very real global threat into the public consciousness. Thank You for setting the stage to develop a strategy for preserving human civilization as we know it and the sentient species who inhabit the biosphere. Your latest study, "Assessing 'Dangerous Climate Change': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature," has further articulated a higher, more urgent imperative for immediate climate remediation. [3]

[1] World Business Academy, http://worldbusiness.org.
[2] http://worldbusiness.org/about/fellows/
[3] Hansen J., Kharecha P., Sato M., Masson-Delmotte V., Ackerman F., et al. (2013), "Assessing 'Dangerous Climate Change': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature," PLoS ONE 8(12): e81648. doi:10.1371/journal.pone.0081648, December 3, 2013.

These findings also appear to be confirmed by The Geological Society, who in a December 2013 addendum to its 2010 climate change report, finds that “[r]ecent research has given rise to the concept of ‘Earth System sensitivity’, which also takes account of slow acting factors like the decay of large ice sheets and the operation of the full carbon cycle, to estimate the full sensitivity of the Earth System to a doubling of CO2. It is estimated that this could be double the climate sensitivity.”[4]

The World Business Academy agrees with the substantive findings from these reports and is firmly committed to implementing the most expeditious path towards (i) eliminating or mitigating all sources of carbon and methane emissions and (ii) remediating ambient CO2 levels back to pre-industrial levels. After 15 years of research, the World Business Academy has approached this issue from a neutral standpoint and determined that due to cumulative, long-term thawing of the permafrost region and Albedo Effect impacts, the global environment is deep in a negative feedback loop exacerbated by increasing glacial and ice sheet runoff. Even if we were to achieve zero carbon emissions tomorrow, it would be too late for the global environment to self-remediate within the recognizable future without active human intervention in the form of various geoengineering solutions to supplement a zero carbon emission approach. As you know, CO^2 is already at 406ppm globally and is shooting perilously upward on an increasing trajectory. This will prove non-survivable for the mass of humanity trapped by a climate-induced “insanity” that will likely surprise us with its ferocity in challenging human civilization.

As was noted in the final finding of fact in the most recent IPCC report, a reduction of CO^2 *by more than 100%* is required to begin to bring the planet back to stability and safety.[5] Without a reversal of CO^2 emissions, we are approaching the tipping point where sequestered methane deposits located beneath the ice tundra and ocean depths are exposed, resulting in a massive release (rather than the constant “tickle” we are now experiencing) that will exponentially increase the resources needed to reverse the climate crisis. In short, the human race does not have the luxury of a “do over” when formulating climate strategy. We have to begin reversing the increasing levels of CO2 and ambient methane *right now*. We are out of time!

Given the urgency of the climate related issues you champion, with which we are in total agreement, we are nonetheless deeply vexed with your proposal to embrace nuclear power in fighting climate change. As delineated in a joint letter published on November 3rd by you, Kenneth Caldeira, Kerry Emanuel, and Tom Wigley,[6] it appears that you may not be as fully informed about nuclear fission as you are informed about climate change. We would like to assist with developing a greater knowledge base about nuclear issues out of respect for the incredible scientific integrity you clearly possess.

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[4] Summerhayes, C.P., Cann, J.W. Wolff, E.W., et al, “An addendum to the Geological Society Statement on Climate Change: Evidence from the Geological Record,” The Geological Society, December 2013.

[5] IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 26.

[6] “Top climate change scientists' letter to policy influencers,” CNN World, November 3, 2013.

A letter, dated January 6, 2014, has already been sent to you by The Civil Society Institute and Nuclear Information and Resource Service which was co-signed by over 300 organizations world-wide, rebutting the assumptions set forth in your November 3rd letter and presenting arguments against the use of nuclear power to mitigate climate change.[7] The World Business Academy was a contributing signatory to the CSI/NIRS letter and proposes in this communication to expand on those arguments and provide additional reference materials in support of our assertions.

My first book on nuclear energy, "Profiles in Power," was co-authored with Professor Jerry Brown of the Academy and was published in 1997 by the textbook division of Simon & Schuster. From that time forward, the Academy has maintained a permanent research effort on virtually every aspect of nuclear power, has published very frequently on the subject, and has continuously sought solutions for society to mitigate the most harmful side effects of nuclear fission. We are hopeful that further elaboration of the challenges associated with nuclear power will persuade you to embrace more economic, more readily available, and more certain renewable energy technologies which will surpass the nuclear industry's alleged ability to assist in mitigating climate change without *any* harmful side effects. All that we ask is that you give what follows a fair and impartial review. We are confident that, as a scientist with an outstanding global reputation, an impartial review will speak to you more convincingly than the rationale in support of nuclear power asserted by some of your climate change colleagues.

It is our contention that those who tout nuclear power as a carbon-free solution to global warming are missing the forest *and* the trees. First, the forest: nuclear power plants continuously emit low levels of cancer-causing strontium-90 radiation during "normal" operations, and higher levels when there are serious problems such as the continuing leakage of radioactive water from the tsunami-damaged reactors at Fukushima, or the radiation leak that lead to the instantaneous closure of the San Onofre nuclear reactor in Southern California in January 2012[8]. Today, even as radiation levels surge in Japan, media pundits discuss the dangers of radiation as if radiation sickness were limited to instances in which people experience nausea, diarrhea, vomiting, or death. This is false. A host of studies show that radioactive emissions of deadly strontium-90 during nuclear plants' routine operations increase cancer rates among those who live near the plants, especially in women and children.[9] (See Appendix A,

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[7] Civil Society Institute/Nuclear Information and Resource Service, Letter dated January 6, 2014, http://www.nirs.org/climate/background/hansenletter1614.pdf.

[8] The World Business Academy was the only business group that participated as a state-authorized Intervener in the hearings which lead to the permanent closure of the San Onofre reactor in Orange County California on June 7, 2013, and continues to appear before the California Public Utilities Commission ("CPUC") as an Intervener seeking to recover $1.5 billion dollars from Southern California Edison for its extraordinary overcharges to ratepayers and for its failure to tell the truth to either the CPUC or the Nuclear Regulatory Commission ("NRC") regarding the substitution of faulty steam generator units that were *not* "like kind" exchanges. The NRC in late December, 2013 issued a citation against Southern California Edison unmasking its illegal conduct.

[9] Joseph J. Mangano et al., "An unexpected rise in strontium-90 in U.S. deciduous teeth in the 1990s," The Science of the Total Environment, December 2003, 317:1-3: 37-51. *See also* Joseph J. Mangano et al., "Infant death and childhood cancer reductions after nuclear plant closing in the U.S.," Archives of Environmental Heath, 2003, 58(2):

Average Strontium-90 in U.S. Baby Teeth, 1954-2013.) The Academy is currently funding a study that will analyze cancer clusters by zip code in Central California from Strontium-90 emissions occurring at the Diablo Canyon nuclear facility. The initial results are indeed alarming and we'll report on the full study when it is completed in less than 60 days.

Next, the trees: nuclear power plants are not "carbon free." They do not emit carbon or other greenhouse gases as they split atoms during the fission process, but their carbon footprint must be assessed on the basis of their complete nuclear fuel life cycle. Significant amounts of fossil fuel are used indirectly in mining, milling, uranium fuel enrichment, plant and waste storage construction, decommissioning, and ultimately transportation and millennia-long storage of waste. There is plenty of carbon in that footprint that is rarely acknowledged, computed, or mediated. In addition, the nuclear industry's false refrain that nuclear power plants have no carbon footprint is an attempt to obscure the fact that nuclear power plants' *radiation footprint* is far more lethal than the carbon footprint of any other industry. Additionally, the industry's rhetoric masks the astronomical costs for thousands of years of storage that could be better invested in rapidly developing renewable fuels with a zero carbon footprint like solar, wind, geothermal, and Ocean Thermal Energy Conversion, which don't carry harmful, let alone lethal, side effects.

Based on the foregoing observations, I and my World Business Academy colleagues would like to engage with you and your panel in a constructive dialogue to examine, from a rational, neutral perspective, the prospects of various forms of energy in relation to the climate change imperative with respect to the following points as expressed in your joint letter:

"The development and deployment of safer nuclear power systems is a practical means of addressing the climate change problem." The arguments that nuclear power offers the solution to climate change are dead wrong for several reasons: (a) no matter how fast you try to build new nuclear plants, there aren't enough engineers and technicians with the required expertise to build the number of nuclear power plants needed during the next 30 years *just to replace the existing nuclear power plants set to go off line, let alone build 1,000 new power reactors in the U.S. alone;* (b) Even if you could build hundreds of new nuclear plants, private sector investors will not fund existing plants or even the *proposed* new generation of multi-billion-dollar nuclear plants, even with massive government guarantees and subsidies, because no one has figured out how to build one that doesn't routinely emit toxic levels of radioactivity while still producing power economically. This "next generation" promise has been heard for many decades now – even as the cost to build old style plants has accelerated by high multiples of their original projected costs just a couple of years ago—no one has yet come up with a viable "next generation" design[10]; (c) nuclear power is grotesquely uneconomical when factoring costs of

74-82. *For further studies, see* Sternglass, Ernest, J., "Articles, Scientific Papers, Books, Letters, and Selected Testimony Relating to the Health Effects of Ionizing Radiation," Radiation and Public Health Project.

[10] The so-called "pebble reactor" has proven to be both uneconomical in design, and in beta testing, unreliable as a means of keeping the fuel "pebbles" safely contained within the reactor core. No utility in the world currently has plans to attempt to build such a device.

construction, operation, decommissioning, and waste disposal/storage for millennia; (d) radioactive emissions from nuclear reactors cause cancer and there is no known solution for radioactive waste disposal; and (e) nuclear power technology creates a path for rogue nations to build nuclear weapons, or as we say in the Academy: "Nuclear power is the gateway drug to nuclear weapons."

From a business perspective, private investors should be seen as the ultimate "referees" on competing energy choices, using informed diligence and prudent criteria to determine which energy technologies can compete in the market with the best chance of generating revenues and profits. As Amory Lovins points out, the capital markets have already spoken. Private investors and project finance lenders have flatly rejected large base-load nuclear power plants and have enthusiastically embraced supply-side competitors, decentralized cogeneration, and renewables.[11] Even the existence of massive government guarantees and subsidies are an inadequate inducement for sophisticated investors like Warren Buffet, whose MidAmerican Energy Company (a 2nd-tier subsidiary of Berkshire Hathaway) scrapped plans for a virtually "free" nuclear power plant[12] while having concurrently formed an affiliated subsidiary, MidAmerican Renewables, dedicated exclusively to the development of renewable energy.[13] We believe the reason *all sophisticated investors* avoid nuclear investments is because no one has figured out how to build a reactor that doesn't routinely emit toxic levels of radioactivity while still producing power economically, and because there is no safe disposal system known to humanity.

The commercial nuclear industry has been around for over half a century, so the prudent approach would be to look at the industry's track record. Under close examination, we find a string of broken promises, product failures, massive subterranean leaks of liquid nuclear waste (e.g., the Hanford facility), cost overruns, overly optimistic projections, stranded debts, bankruptcies, bond defaults, premature plant closings resulting from bad plant siting and/or accidental radioactive emissions from core reactor equipment failures (e.g., San Onofre), and vast quantities of toxic waste that grows daily primarily in spent fuel pools as inviting targets for terrorism. The above account does not include a series of catastrophic accidents and near-accidents, the most memorable of which are the 1979 near-meltdown at Three Mile Island, the 1986 Chernobyl disaster and the ongoing leakage from three failed reactors in Fukushima.

After decades of subsidies, nuclear power still remains the most expensive and non-competitive form of base power generation that takes decades of lead-time before a single electron is produced.[14] Nevertheless, in attempting to promote nuclear power, industry advocates focus only on certain limited costs for heavily subsidized fuel, labor, materials, and services that are characterized as "production costs." But these limited costs are only part of the economic picture. The real challenge facing nuclear

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[11] Lovins, Amory B., "Competitors to Nuclear: Eat My Dust," Rocky Mountain Institute, Newsletter, Summer 2005, p. 26. See Also McMahon, Jeff, "New-Build Nuclear is Dead: Morningstar," Forbes.com, November 10, 2013.
[12] "$1 Billion Nuclear Power Project Abandoned In Iowa," CleanTechnica.com, June 6, 2013.
[13] "Buffett's MidAmerican Energy Holding Forms Renewables Unit," GreenTechMedia.com, January 26, 2012. *See Also*: "Just the Facts: MidAmerican Renewables," MidAmerican Rewewables website.
[14] "Nuclear Power: Still Not Viable Without Subsidies," Union of Concerned Scientists, 2011, pp. 1-10.

power becomes clear when "life cycle" production costs are compared, including construction, operations, maintenance, fuel, decommissioning, *and* millennial waste storage.[15]

The serious challenges described above make nuclear technology a very bad deal. Nuclear advocates claim that safety concerns will be addressed by the next generation of new advanced reactor designs that are supposedly "inherently safe." This appears to be a backhand admission that the first-generation reactors were not that safe in the first place. And, as noted elsewhere herein, after hearing promises of a "next generation" reactor designs for many decades, no such design has appeared that is remotely ready for commercial construction. How long can all the acknowledged ills of nuclear power be cavalierly wiped away by invoking a mythical "next generation" reactor that has never appeared nor is likely to appear?

Before rushing to endorse nuclear expansion, regulatory agencies and individual researchers should critically examine past performance and demand experimental proof for claims that the next generation of nuclear plants (should any ever be considered for construction) will be economically viable, climate-friendly, and accident-proof. It is believed that next generation reactors will differ dramatically from current reactors in that they will replace active water cooling and multiple backup safety systems with "passive safety" designs. In fact, many nuclear advocates and news reports inaccurately describe the *proposed* new reactor designs, such as the pebble bed modular reactors, as "accident-proof" or "fail-safe." However, experiments conducted at the THTR-300 modular reactor in Germany led to accidental releases of radiation after one of the supposedly "accident-proof" fuel pebbles became lodged in a feeder pipe, damaging the fuel cladding. After the operators tried to conceal the malfunction and blamed the radiation release on the Chernobyl accident, the government closed the reactor.[16]

The U.S. government has previously promised that there would be a long-term solution for the storage of high-level radioactive waste, primarily from spent fuel rods, which are still sitting in underwater spent fuel pools at "temporary" reactor storage sites around the country. The Department of Energy's now defunct long-term waste depository at Yucca Mountain, Nevada, was mired in scientific controversy, legal challenges, and an admission by all concerned that it wouldn't prove large enough to contain the waste being created by existing reactors—let alone deal with the radioactive waste from new ones. Because of the lack of federal disposal facilities, highly radioactive spent fuel has to be removed regularly from the reactor core and "temporarily" stored in on-site water-filled cooling pools. While a variety of disposal methods have been under study for decades, there is still no demonstrated solution for effectively isolating and storing nuclear waste from the environment for many thousands of years. Meanwhile, high-level radioactive waste continues to build up at 65 reactor sites in 31 states in spent fuel pools without reinforced containment buildings that are vulnerable to accidents and terrorist attacks.

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[15] "Nuclear Power: Still Not Viable Without Subsidies," Union of Concerned Scientists, 2011, pp. 7-9.

[16] "'Inherently Safe' German PBMR Covers Up Radiation Accident and Shuts Down," Nuclear Information and Resource Service.

Once again, the promises of safety are enticing, but this time around the buyer had best demand the most rigorous levels of experimental verification. As Edward Teller, father of the H-bomb, observed, "Sooner or later the fool will prove greater than the proof even in a foolproof system."

"Renewable energy sources like wind and solar and biomass cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires." Renewable energy sources, such as wind, solar and geothermal, are imminently scalable when combined with hydrogen fuel cell technologies to store and transport the energy they create. Renewables do not require the enormous planning and construction timeframes that plague nuclear units. Renewables are not prone to cost overruns, are cheaper to build and operate than nuclear plants, and produce power with zero carbon emissions. As such, they represent the least costly and least risky investment opportunities. In fact, Jacobson and Delucchi have argued persuasively in a November 2009 *Scientific American* article that "Wind, water and solar technologies can provide 100 percent of the world's energy, eliminating all fossil fuels."[17] In fact, our experience to date with renewable sources of energy is that their economies of scale and abundant status ultimately drive the cost of energy down over time, as opposed to finite fossil fuels and undeveloped 4th-generation nuclear energy technology.

In addition to all the other insurmountable challenges of using nuclear fission to create energy, the percentage of global energy supply generated by nuclear has actually fallen significantly in the recent past and shows every likelihood to fall even further in the coming decade. Over the last decade, renewables and combined-heat-and-power systems (cogeneration or distributed power) actually overtook nuclear power generation. The former, by 2010, represented 18% of the world's electric generation while nuclear represented a mere 13%.[18]

Wind power and photovoltaic supply sources have become particularly strong growth sources of renewable energy. Since 2000, the annual growth rate for global wind power has been 27%; for solar PV 42%.[19] From 2002 to 2012 in the US, nearly 50,000 megawatts of wind were installed. Currently, the US installs a solar system every 4 minutes. That's expected to grow to one new system every one minute by 2015. And the numbers are accelerating. Two-thirds of all distributed solar systems have been installed over just the last 2 ½ years. By 2016, Greentechmedia research projects the US will have one million residential solar PV installations.[20] Worldwide solar is expanding at a feverish pace. In four decades, 50,000 megawatts of solar PV were installed globally. But an additional 50,000 were added just over the last 2 ½ years while panel prices have fallen 62%. By 2015, another 100,000 megawatts are projected to be installed. [21] In 2012, almost half of all generation capacity additions in the U.S. were renewable. In

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[17] Jacobsen, Mark Z., and Delucchi, Mark A., "A Path to Sustainable Energy by 2030," Scientific American, November 2009.
[18] Lovins, Amory, "With Nuclear Power, 'No Acts of God Can be Permitted,'" Huffington Post, March 18, 2011.
[19] "World Nuclear Industry Status Report: 2013," Mycle Schneider Consulting, July 2013.
[20] "Solar System Installed in US Every 4 Minutes," Greentechmedia, August 13, 2013.
[21] "Chart: 2/3 of Global PV have been Installed in Last 2.5 Years," Greentechmedia, August 13, 2013.

January of this year, all capacity additions were renewable. Most of that was wind and solar PV.[22] From January through September last year in the U.S., 961 megawatts of wind and 1,935 megawatts of solar PV were installed. No nuclear additions occurred.[23] Why slow down these two dramatically effective sources of energy by allocating many billions of dollars per year to "develop" more nuclear resources that cannot be quickly deployed given various siting issues (long lead time, environmental safety, etc.) that will continue to keep nuclear bottled up and in decline in all modern, western industrialized nations?

Nuclear power hasn't seen the same success as its renewable competitors for the public's cash. Its percentage of global energy generation dropped 7% from a peak of 17% in 1993 to 10% in 2012. Currently, 14 countries are building 66 nuclear reactors worldwide. Forty-four of them are being constructed in China, India, or Russia. Nine of the 66 have been listed as "under construction" for 20 years; four for 10 years. Forty-five of them have no start-up date and 23 have experienced significant, protracted construction delays.[24]

All the renewable technologies such as wind, photovoltaic, so-called "Power Towers" (commercial-scale arrays of mirrors to create base power from solar exposure), and geothermal are mature and can be deployed immediately, given the requisite political will, whereas "next generation" nuclear reactors are still in the theoretical stages and have yet to produce a working scalable prototype. Indeed, according to the Office of Nuclear Energy estimates, "Some of these revolutionary designs could be demonstrated within the next decade, with *commercial deployment beginning in the 2030s*."[25] That's clearly *far too late* to assist with reducing carbon emissions if we want to avoid mass calamity. Nuclear energy's technological deficiency did not go unnoticed by former Vice President Al Gore, a former supporter of nuclear energy, who recently modified his position and said the current state of technology in the nuclear energy industry did not yet warrant a big expansion.[26] Where will we be with climate change by the 2030s if we can't, even by the most optimistic assessment from industry advocates, begin to build significant numbers of new plants? We can't wait that long to act. Renewables are here *today*. They are proven, *today.* They are particularly desirable now that we have all the technology we require to store 100% of the power from renewables in the form of gaseous hydrogen for use by stationery and mobile fuel cells.[27]

[22] "Nearly Half of New US Power Capacity in 2012 Was Renewable – Mostly Wind," Grist.org, Jan 18, 2013
[23] "Office of Energy Projects: Energy Infrastructure Update," Federal Energy Regulatory Commission (FERC), September 2013.
[24] "World Nuclear Industry Status Report: 2013," Mycle Schneider Consulting, July 2013.
[25] Kelly, John E., Dep. Asst. Sec. for Nuclear Reactor Technologies, Office of Nuclear Energy, "Paving the Path for Next-Generation Nuclear Energy," May 6, 2013 (para.s 2 & 4). Italics added.
[26] The Guardian, January 15, 2014.
[27] Hyundai is selling the first commercially available hydrogen powered electric car in California by May, 2014, followed shortly after that by Toyota, Honda and ultimately a year or so later by 6 other manufacturers. See "Hyundai to offer Tucson Fuel Cell vehicle to LA-area retail customers in spring 2014; Honda, Toyota show latest FCV concepts targeting 2015 launch," Green Car Congress, November 11, 2013.

Furthermore, it is the Academy's considered opinion that the days of constructing centralized base load power systems of any type are over, and the future of carbon-free energy production lies in decentralized systems. Rapidly accelerating the integration of gaseous hydrogen and hydrogen fuel cells into the grid allows for a decentralized power structure that can both work with, or independently from, the current electric power infrastructure. This feature is particularly important when 1) converting an existing modern grid supplied electrical system in phases, 2) in scaling power systems for emerging third-world countries that cannot easily accommodate power grid infrastructure, or 3) supplementing renewable energy with hydrogen and hydrogen fuel cells that can provide both storage capacity and grid stability.

The business case for hydrogen/fuel cell power can be summarized as follows[28]:

"Fuel cells are reliable, efficient, quiet, and significantly cut carbon emissions (and eliminate them when hydrogen is created by electrolysis from renewable energy sources). In the age of distributed generation (power generated onsite), fuel cells also offer facilities a clean break from an electric grid plagued by violent weather disruptions, line losses of up to 40% of the energy actually delivered, susceptibility to forest fires,[29] and growing issues with cyber security. In addition, fuel cells are compatible with other energy technologies – whether renewable such as solar, wind or biogas, or traditional, such as natural gas or batteries. Fuel cells complement and improve energy technology performance and, in turn, help companies meet their sustainability goals while boosting their bottom line. … Fuel cell systems, whether grid-tied or grid-independent, provide premium power without voltage sags, surges, and frequency variations that can impact computer systems. In addition to power, byproduct heat from a fuel cell can be used at the end-user facility for space heating, water heating, and chilling, resulting in a combined electric/heat efficiency of ~85%. When supplementing grid power, fuel cells reduce peak demand and lower energy bills. … Fuel cell systems can be scaled up to multi-megawatts [30] and are capable of taking entire corporate campuses off the electric grid, but they do not have to work alone. In fact, many facilities now use fuel cells alongside other energy technologies to meet their power needs."

"Innovation and economies of scale can make new power plants even cheaper than existing plants." The historically consistent record of nuclear reactors for over 50 years is exactly the opposite – they have gone up each year in cost and have never achieved economies of scale or brought prices down. To our knowledge, there is no evidence supporting the proposition that either innovation or "economies of scale" will result in cheaper nuclear power in the future and, as noted earlier, no functional design exists

[28] Curtin, Sandra, et al, "The Business Case for Fuel Cells 2012," pp. 1-4, Fuel Cells 2000.
[29] In fact, long distance transmission lines are not only destroyed by the increasing pattern of forest fires in the Western USA, they are often determined to be *the cause* of the fires themselves which then rage out of control in remote parts of the forest.
[30] South Korea has begun installing and using such large base power fuel cell generators. See Dixon, Darius, "Another U.S. Clean Energy Generator Finds a Home Abroad," New York Times, June 24, 2010.

(or is on the drawing board) that will lead to reduced costs for nuclear energy in the foreseeable future. The economic challenge facing nuclear power becomes clear when one faces the fact that its "life cycle" production costs, computed on a per kilowatt-hour basis, are several times that of coal, natural gas, and wind — not including the ultimate waste disposal costs which remain unknown because no approved disposal system exists in the U.S.

Even if we decided to replace all fossil-fuel plants with nuclear reactors – leaving cost issues aside – it would not be technically possible to build them quickly enough to meet even the modest targets of the Kyoto Protocol. In the U.S., up to 1,000 new reactors (nearly 10 times the current base) would be required at a cost of about $1.5 trillion to $2.0 trillion, based on industry estimates of $1,500-$2,000/KW for new nuclear plant construction. In fact, Alvin M. Weinberg, former director of Oak Ridge National Laboratory argues that, in order to make a serious dent in carbon emissions, it would take perhaps four times as many reactors as suggested by the MIT study, or up to 4,000 reactors.[31]

In terms of upfront capital costs, an August 2013 analysis by Lazard is revealing. Whereas new nuclear construction stands at an average of nearly $7,600 per kilowatt, new onshore wind and solar PV (whether rooftop or utility scale) is much lower. Wind ranges, according to Lazard, between $1,500 to $2,000 per kilowatt and the high price for solar PV (rooftop) is assessed at $3,500 per kilowatt. Even offshore wind (which receives little to no subsidies from the US government) is competitive with new nuclear power units at an estimated $4,050 per kilowatt.[32] Although the levelized cost of solar PV (the average cost over its lifetime) is estimated to be larger than Lazard's estimated nuclear levelized cost, no one actually knows the final cost of a new nuclear plant in the U.S., and, given constant construction delays, if any can be built. Onshore wind and solar PV reached the cost threshold depicted by Lazard over the last decade or less. And their costs continue to decline. In fact, in the last four years estimates are that onshore wind and solar PV's average lifetime costs have dropped 50%.[33]

The trend is well recognized by Wall Street analysts. For instance, Citi Research declared in the fall of 2012 that solar was already cheaper than retail electric rates "in many parts of the world…" Citi analysts wrote, "The perception of renewables as an expensive source of electricity is largely obsolete…"[34] Best of all, we can construct these proven resources at a rapid pace even as we bring additional geothermal and Ocean Thermal Energy Conversion (OTEC) resources on line. The supply is limited only by our will to make the conversion to renewables our chosen path. The amount of energy that can be created at increasingly *lower* costs is virtually limitless with very little lead time (e.g. a new wind farm can go from siting to full production in 6-9 months).

According to a comment in the May 22nd edition of Environmental Science and Technology, issued in rebuttal to your March 15th article "Prevented Mortality and Greenhouse Gas Emissions from Historical

[31] Weinberg, Alvin M., "New Life for Nuclear Power," Issues in Science and Technology, Summer 2003.
[32] "Levelized Cost of Energy Analysis – Version 7.0," Lazard, August 2013.
[33] "Analysis: 50% Reduction in Cost of Renewables Since 2008," Cleantechnica.com, September 11, 2013.
[34] "Shale and Renewables: A Symbiotic Relationship," Citi Research, September 12, 2012.

and Projected Nuclear Power," the authors asserted that ". . . [E]ven if nuclear energy could save lives, it does so at a substantially higher financial, environmental, and political cost than alternatives. . . . [W]hen recent marginal capital and levelized costs are factored in for the United States, wind energy is 96 times more effective at displacing carbon than nuclear power; other renewable sources range from about 20 times to twice as effective. Indeed, The U.S. Congressional Budget Office estimated nuclear power plant construction costs from 1966 to 1977, when most light water reactors in the U.S. were built, and found that the quoted cost for these 75 plants was $89.1 billion, but the real cost was $283.3 billion. These cost overruns have every likelihood of affecting future plants."[35]

"Quantitative analyses show that the risks associated with the expanded use of nuclear energy are orders of magnitude smaller than the risks associated with fossil fuels." While this assertion may be accurate on its face, it is in fact a red herring: choosing between nuclear and fossil fuels is like comparing death by hanging or by firing squad. The real question concerns the comparison between the associated cost and risks from a massive increase in nuclear power plant construction to the risks related to a similar expansion of renewable energy and hydrogen economy technologies. I think you would agree that there is little to no risk from renewable energy. Conversely, there remains significant exposure from nuclear power, even from *highly* theoretical generation 4 plant technology which claims to result in reduced waste, higher efficiencies and lower exposure to the surrounding population but is not remotely ready for commercialization at this time.

The captive nature of the Nuclear Regulatory Commission (NRC) to the nuclear industry also brings into question the ability of the U.S. to ensure safe operation of existing or new nuclear power plants. Unfortunately for us all, the NRC has the twin duty of "promoting and regulating" nuclear power. There is no question, after decades of experience, that "promotion" wins out every time over "regulation." In 2011, the Associated Press issued a highly critical report documenting the cozy relationship between the NRC and the nuclear industry. AP found that safety standards were purposely weakened to allow aging reactors to continue operation.[36] AP's assertion that the institutional bias within the NRC is to protect rather than regulate the nuclear industry is reinforced by the Union of Concerned Scientists 2012 report about nuclear power plant safety. The 2012 report is one in a series that documents "near misses" at nuclear power plants. UCS defines a near miss as "an event that increases the chance of a core meltdown by at least a factor of 10…" The report found that NRC "has repeatedly failed to enforce essential safety regulations." In its reports from 2010 to 2011, UCS documented 56 near-misses at 40 reactors, which means some operators are chronic violators of the law. [37]

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[35] Sovacool, Benjamin K., et al, "Comment on 'Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power'," [dx.doi.org/10.1021/es401667h], Environ. Sci. Technol. 2013, 47, 6715−6717, p. 6715, para. 4 (see footnotes infra).
[36] "Part I: AP IMPACT: US Regulators Weaken Nuke Safety Rules," AP, June 2011.
[37] "The NRC and Nuclear Power Plant Safety in 2012: Tolerating the Intolerable," UCS, 2012.

Gregory Jaczko, who was chairman of the U.S. Nuclear Regulatory Commission at the time of the Fukushima Daiichi accident, recently argued that more Fukushima-type accidents are inevitable if the world continues to rely on the current types of nuclear fission reactors, and he believes that society will not accept nuclear power on that condition. "For nuclear power plants to be considered safe, they should not produce accidents like this," he said. "By 'should not' I don't mean that they have a low probability, but simply that they should not be able to produce accidents like this. That is what the public has said quite clearly. That is what we need as a new safety standard for nuclear power going forward."[38] In fact, just after leaving office on April 8, 2013 Chairman Jaczko made the shocking observation that all 104 then operating nuclear power plants in the U.S. have safety problems that cannot be fixed and that they should be replaced. He went on to observe "Continuing to put Band-Aid on Band-Aid is not going to fix the problem."[39]

Mr. Jaczko's sentiments are reverberating throughout Japan, whose citizens are feeling first-hand the devastating consequences of nuclear disaster. As reported in The Guardian: "Since Fukushima, a forceful grass-roots movement has grown to permanently decommission all of Japan's nuclear power plants. The prime minister at the time of the earthquake, Naoto Kan, explained how his position on nuclear power shifted: 'My position before 11 March 2011, was that as long as we make sure that it's safely operated, nuclear power plants can be operated and should be operated. However, after experiencing the disaster of 11 March, I changed my thinking 180 degrees, completely ... there is no other accident or disaster that would affect 50 million people -- maybe a war, but there is no other accident can cause such a tragedy.' Prime Minister Abe, leading the most conservative Japanese administration since World War II, wants to restart his country's nuclear power plants, despite overwhelming public opposition." In response to the widespread unrest, the current administration also enacted a controversial state secrecy law that has been used to suppress dissent and transparency concerning the true impacts from the Fukushima meltdown.[40] In response, independent volunteer groups such as Safecast have gathered their own radiation data through crowdsourcing Geiger readings from Fukushima to Tokyo. After three years, their data shows that radiation levels in Tokyo (200 km. away) have increased 50% since Fukushima.[41] The World Business Academy plans on employing similar techniques to monitor Fukushima impacts along the western US coastline. All evidence concerning the social and environmental impacts of Fukushima must be weighed before Mankind "goes all in" on nuclear energy.

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[38] Strickland, Eliza, "Former NRC Chairman Says U.S. Nuclear Industry is 'Going Away'," IEEE Spectrum, October 10, 2013. *See also the following video*: "Gregory Jaczko: Dangers of Nuclear Power in New York," The Fukushima Daiichi Nuclear Accident: Ongoing Lessons, https://www.facebook.com/FukushimaLessons, October 8, 2013.
[39] Wald, Matthew, "Ex-Regulator Says Reactors Are Flawed," New York Times, April 8, 2013. Chairman Jaczko served as Chairman of the NRC from May 2009 to May 2012.
[40] Goodman, Amy, "Fukushima is an ongoing warning to the world on nuclear energy," The Guardian, January 16, 2014.
[41] "Volunteers Crowdsource Radiation Monitoring to Map Potential Risk on Every Street in Japan," DemocracyNow.Org, January 17, 2014. See Also, Safecast website.

“We cannot afford to turn away from any technology that has the potential to displace a large fraction of our carbon emissions.” As stated above, the “life cycle” production costs of nuclear energy, computed on a per kilowatt-hour basis, are several times that of photovoltaic, geothermal, wind, and likely OTEC as well. In your article, “Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power,” you and co-author Pushker A. Kharecha state that

> “[i]f the role of nuclear power significantly declines in the next few decades, the International Energy Agency asserts that achieving a target atmospheric GHG level of 450 ppm CO2-eq would require ‘heroic achievements in the deployment of emerging low carbon technologies, which have yet to be proven.’ […] Our analysis herein and a prior one strongly support this conclusion. Indeed, on the basis of combined evidence from paleoclimate data, observed ongoing climate impacts, and the measured planetary energy imbalance, it appears increasingly clear that the commonly discussed targets of 450 ppm and 2 °C global temperature rise (above preindustrial levels) are insufficient to avoid devastating climate impacts; we have suggested elsewhere that more appropriate targets are less than 350 ppm and 1 °C. Aiming for these targets emphasizes the importance of retaining and expanding the role of nuclear power, as well as energy efficiency improvements and renewables, in the near-term global energy supply.”[42]

While we at the World Business Academy agree with your overall assessment concerning higher standards and the need for action, we believe that the vast resources and time needed to build new nuclear plants on a scale to meaningfully reduce carbon emissions would be better allocated towards the expansion of various renewable energy sources in tandem with hydrogen storage and transport systems. If the impact you seek is an expedited and meaningful reduction in global greenhouse gas emissions, the fastest, most economically viable and safest course of action is an all-out effort to ramp up renewable deployment. With the support of the private sector, the growth and innovation in the renewable energy sector will lead to unprecedented adoption of the technologies critical to the future of our species.

If a business fails, the owners face bankruptcy. If nuclear power fails, the world faces radioactive poisons, nuclear terrorism, and the specter of a dangerous future filled with bomb-rattling nations and regional nuclear arms races. We face incalculable expense and unlimited danger dealing with ever-greater quantities of highly toxic radioactive waste that remains deadly even in small quantities for millennia.

Our civilization immediately needs to deploy on a massive scale non-fossil fuel energy sources that (1) are safe, renewable, non-toxic, and increasingly inexpensive (as deployed quantities increase) and (2) can begin supplying vast amounts of sustainable energy on a fully distributed basis (i.e., where creation

[42] Kharecha, Pushker A. and Hansen, James E., “Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power,” [dx.doi.org/10.1021/es3051197], Environ. Sci. Technol. 2013, 47, 4889–4895, p. 4893, para. 7.

and utilization are both distributed). Given growing demand and limited resources, the U.S. and the nations of the world should invest in the best global energy solutions rather than try to resurrect the failed nuclear option. Efficiency, biofuels, renewables, and hydrogen could revitalize our nation and our planet economically, environmentally, and geopolitically, while ensuring a safe future for all.

We at the World Business Academy are working to realize that vision and are preparing a plan, reminiscent of JFK's 1961 "Moonshot Challenge," to make the state of California carbon-free within 10 years of implementation. Under our plan, scheduled for publication in 2014 in conjunction with hearings before the California Public Utilities Commission, an infinite supply of wind ($0.08/KW) and geothermal ($0.10/KW) energy will be converted into hydrogen at a cost of $7.50/kg, or approximately $3.25/gal equivalent. Concurrently, chemical and catalytic technologies would be pursued to extract carbon from the atmosphere, and to solidify those deposits into plastics for beneficial use. Should California, the world's 8th largest economy, successfully meet this challenge, we believe the world will follow.

Even though the current energy system is entering its sunset years—in fact because of it—our basic findings are overwhelmingly positive. Civilization has already survived, indeed prospered, through several profound energy transformations: from muscle power to wood; from wood to coal and whale oil; and most recently from coal and whale oil to petroleum and natural gas. We firmly believe it is within our collective power and wisdom to call forth the leadership needed to replace fossil fuels, minimize and eventually stabilize climate change, create a stronger and more secure global economy, and spread wealth to poor nations.

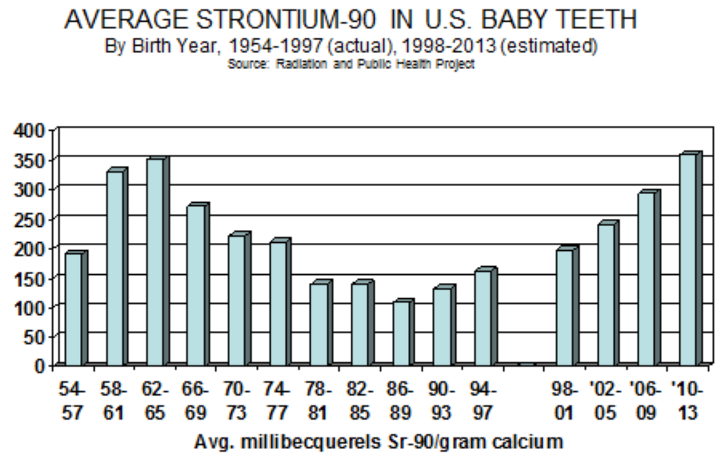
In closing, I would like to emphasize that all of us engaged in the fight to mitigate climate change are on the same side, and our only difference lies in what we see as the best path forward for humanity. Unfortunately, we do not have the luxury of pursuing multiple paths towards a solution given the accelerating timeline identified by your research and the finite human, physical and political capital at our disposal.

We would love an opportunity to discuss these issues in detail and collaborate on ways to advance our mutual goals regarding climate change. By engaging in a constructive dialogue, we can develop the synergies to realize the kind of "heroic achievements" needed to save humanity from itself.

Sincerely,

Rinaldo S. Brutoco
President

Appendix A


AVERAGE STRONTIUM-90 IN U.S. BABY TEETH
By Birth Year, 1954-1997 (actual), 1998-2013 (estimated)
Source: Radiation and Public Health Project
400
350
300
250
200
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58-61
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78-81
82-85
86-89
90-93
94-97
98-01
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'06-09
'10-13
Avg. millibecquerels Sr-90/gram calcium

ABOUT

The World Business Academy is a non-profit business think tank, action incubator and network of business and thought leaders. Our Mission is to inspire business to assume responsibility for the whole of society and assist those in business who share our values.

Led by our Founding President, Rinaldo S. Brutoco, the Academy explores the role and responsibility of business in relation to critical moral, environmental, and social issues of our day.

For more background on the inspiration of the Academy, read our Mission Statement and *Why is There a World Business Academy?*, a foundational document that remains as relevant today as it was when first published in 1987.

The Academy's projects and publications take on today's challenges including environmental degradation; the shift away from dirty energy and toward clean, renewable energy; and the existential threat posed by climate change. Our work explores new metrics for valuation of public companies, value-driven leadership, the development of the human potential at work, sustainable business strategies and global reconstruction.

Housed in the Academy, the annual EthicMark® Awards recognize socially responsible advertising and media communications that uplift the human spirit and society.

The Academy has a unique resource in its Academy Fellows who comprise a veritable Who's Who of world-class thinkers. These include Warren Bennis (leadership and management), Lester Brown (global environment), Deepak Chopra (healing and wellness), Ervin Laszlo (cultural consciousness), Hazel Henderson (economic futures), Amory Lovins (energy policy), Michael Ray (creativity in business), Lance Secretan (inspirational leadership), Peter Senge (organizational learning) and many more.

308 East Carrillo Street Santa Barbara, CA 93101 U.S.A
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WORLD BUSINESS ACADEMY | *Taking Responsibility for the Whole*

Our Fellows

World Business Academy Fellows represent some of the best and brightest men and women who are shaping today's global landscape. For many years, they have analyzed, reported and predicted the transforming paradigm shifts in business and society. Via Academy publications, Fellows provide Members with current information on issues relevant to the evolving global landscape.

Lynne Twist

For more than 40 years, Lynne Twist has been a recognized global visionary committed to alleviating poverty and hunger and supporting social justice and environmental sustainability. From working with Mother Teresa in Calcutta to the refugee camps in Ethiopia and the threatened rainforests of the Amazon…

David Gershon

David Gershon, co-founder and CEO of Empowerment Institute, is one of the world's foremost authorities on behavior-change, community empowerment and large-system transformation, and applies this expertise to issues requiring community, organizational, and societal change. His clients include cities, …

Deepak Chopra, M.D.

Acknowledged as one of the world's greatest leaders in the field of mind body medicine, Deepak Chopra, M.D. continues to transform our understanding of the meaning of health. Through his creation of The Chopra Center For Well Being in La Jolla, California in 1995, Chopra established a formal vehicle…

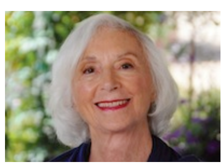
Complete List of Our Fellows

Amit Goswami, Ph.D.

Professor Goswami earned his Ph.D. from Calcutta University in theoretical nuclear physics in 1964 and has been a professor…

Amory B. Lovins, Ph.D.

Amory B. Lovins, Chief Executive Officer (Research) of Rocky Mountain Institute, is a consultant experimental physicist …



Barbara Marx Hubbard, Ph.D.

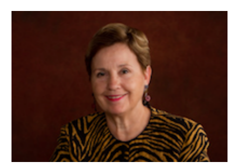
Dr. Barbara Marx Hubbard has been a pioneer in positive options for the future for the past 35 years. A public speaker, …

Ben A. Mancini

Ben Mancini served as President of the World Business Academy from 1997 to 2000. He concurrently held the positions of President…

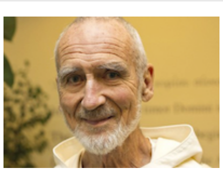
Bernard A. Lietaer

Bernard Lietaer is the lead author of the paradigm-shifting new report by the EU Chapter of the Club of Rome, "Money and…



Beth S. Jarman, Ph.D.

Beth Jarman is a founding partner of Leadership 2000, Inc. Her strong academic and organizational interests have provided…



Brother David Steindl-Rast,

Ph.D.

David Steindl-Rast was born in 1926, in Vienna, Austria, where he received a Ph.D. from the University of Vienna. In 1952…

Corinne McLaughlin

Corinne McLaughlin is co-author of The Practical Visionary: A New World Guide to Spiritual Growth and Social Change,Spiritual…

Cynthia Cherrey, Ph.D.

Cynthia Cherrey, the vice president for student affairs at Tulane University who helped lead the New Orleans school through…

Daniel Goleman, Ph.D.

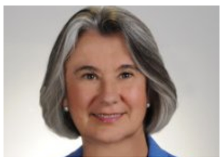
Daniel Goleman consults internationally and lectures frequently to business audiences, professional groups, and college …

David Krieger, Ph.D.

David Krieger is a founder of the Nuclear Age Peace Foundation, and has served as President of the Foundation since 1982…

David L. Cooperrider

David L. Cooperrider is Professor and Chairman of the Department of Organizational Behavior at the Weatherhead School of…



Diana Whitney, Ph.D.

Dr. Diana Whitney is an inspirational speaker, provocative educator and pioneering thought leader in the growing field of…

Diane V. Cirincione, Ph.D.

Dr. Cirincione is a therapist and former postdoctoral clinical researcher at Langley Porter Psychiatric Institute at the…

Dipak C. Jain, Ph.D.

Dipak C. Jain has been named Dean of INSEAD, the international business school based in Fontainebeau, France which also…

Don Beck, Ph.D.

Don Beck, Ph.D. is a prototype for activists in the new millennium. His dedication to service and discovery has seen him…

Dr. Dorothy Maver

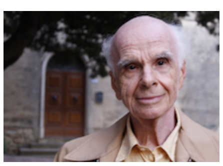
Dr. Dorothy Maver is President of the National Peace Academy, bringing a focus on peacebuilding and peacelearning to the…

Eddie Erlandson, M.D.

Eddie Erlandson brings a unique background as a physician and business leader to helping executives make needed changes. …

Elisabet Sahtouris, Ph.D.

Elisabet Sahtouris, Ph.D. is an evolution biologist, futurist, author, speaker and consultant on Living Systems Design. …



Ervin Laszlo, Ph.D.

Dr. Ervin Laszlo is a Fellow of the World Business Academy. He is the Founder and President of the Club of Budapest, President…

F. Byron (Ron) Nahser, Ph.D.

Managing Director for CORPORANTES, Inc., an outgrowth of The Nahser Agency/Advertising, Dr. Nahser is currently a Senior…

Gary Zukav

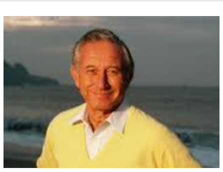
My life is dedicated to the birth of a new humanity. That birth is now in progress. We are all involved in it. The new humanity…

Gay Hendricks, Ph.D.

Gay Hendricks, Ph.D., was Professor of Counseling for twenty-one years in the school of Education at the University of Colorado…

George Land, Ph.D.

George Land is an author, speaker, consultant, and general systems scientist. In 1965 he founded a research and consulting…



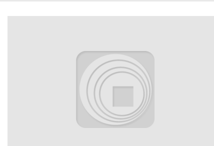
Gerald G. Jampolsky, M.D.

Gordon Davidson

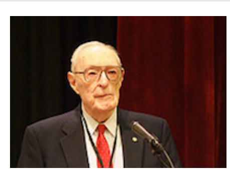
Gordon Davidson is the

Greg Mortenson

Greg Mortenson is the



H. James Brown, Ph.D.



Harlan Cleveland, PH.D.

Harrison Owen

Harrison Owen is

Dr. Jampolsky is a graduate of Stanford Medical School and a former faculty member of the University of California School...

president of the Center for Visionary Leadership and a co-founder of Sirius Community, and he has...

co-founder and Executive Director of the Central Asia Institute, which works to empower communities...

H. James Brown is president and CEO of the Lincoln Institute of Land Policy. From 1970 to 1996, he was a professor at the...

(1918 to 2008)

Dr. Cleveland was born January 19, 1918 and passed away May 30, 2008...

President of H.H.Owen and Co. His academic background and training centered on the nature and function ...

Hazel Henderson, Ph.D.

Hazel Henderson is the founder of Ethical Markets Media, LLC and the creator and co-executive Producer of its TV series. ...

Helen Palmer

Helen Palmer is the author of five international best-selling books in the literature of consciousness. Her works include...

Jagdish Parikh, Ph.D.

Dr. Parikh is Managing Director of the Lemuir Group of Companies, a Director of the TechNova Group of Companies and Travel...

James B. Channon

Recognized worldwide as the original pioneer of the corporate visioning process he has been a trusted strategic designer...

James C. Thompson

Jim Thompson is founder and Executive Director of Positive Coaching Alliance, a non-profit formed at Stanford University...

James Milojkovic, Ph.D.

James Milojkovic (pr. Miloy'ko'vich) is the Founder and Chief Education Officer of KnowledgePassion...

Jayantilal (Andy) K. Chande

Born in Kenya, Andy, who was knighted by Her Majesty Queen Elizabeth II in 2003, is a fellow of the International Academy...

Jean Houston, Ph.D.

Dr. Jean Houston, scholar, philosopher and researcher in Human Capacities, is one of the foremost visionary thinkers and...

Jerry B. Brown, Ph.D.

Over the past three decades, Jerry B. Brown, Ph.D. has worked to create positive social and environmental change through...

Jessica H. Fullmer

Jessica Fullmer is founder and CEO of Mo-DV. Mo-DV was formed in the summer of 2002 to use memory cards for video in mobile...

John Adams, Ph.D.

John D. Adams, Ph.D. has been at the forefront of the Organization Development profession for more than 30 years. He was...

John B. Taylor, Ph.D.

John B. Taylor, Ph.D. is the Mary and Robert Raymond Professor of Economics at Stanford University and the Bowen H. and ...

John Raisian, Ph.D.

Dr. Raisian is an economist who specialized in national and international labor market and human resource issues. Prior ...

Joseph Jaworski

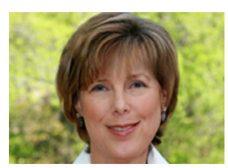
Joseph Jaworski has devoted much of his life to the study and practice of leadership development. He began his professional...

Karen Wilhelm Buckley

Karen Wilhelm Buckley is Principal Consultant with The Wisdom Leadership Initiative, assisting leaders and organizations...

Karl-Hendrik Robert, M.D.

Dr. Karl-Henrik Robèrt is one of Sweden's foremost cancer scientists whose work on damaged human cells led to a deep interest...



Kate Ludeman, Ph.D.

Kate Ludeman is a widely recognized executive coach, speaker and author. In 1988, Kate founded Worth Ethic Corporation. ...

Kirk Hanson

Kirk O. Hanson, executive director of the Markkula Center for Applied Ethics at Santa Clara University, is University Professor...

Lance H. Secretan, Ph.D.

Lance Secretan is a pathfinder and missionary, and one of the world's foremost thinkers about leadership, inspiring people...

Larry Spears

Larry Spears was named Chief Executive Officer of The Robert K. Greenleaf Center for Servant-Leadership in 1990. Spears ...

Lester R. Brown

The Washington Post called Lester Brown "one of the world's most influential thinkers." The Telegraph of Calcutta refers...

Marc Luyckx, Ph.D.

Born in 1942, married with Isabelle, six children, He is living in the neighbourhood of Brussels. He has studied mathematics...

Margaret Wheatley

Margaret Wheatley is president of The Berkana Institute, and an internationally acclaimed speaker and writer. She has been...

Mark Gerzon

Mark Gerzon is one of the key architects of the field of global leadership and global citizenship, an experienced facilitator...

Mark S. Albion, Ph.D.

After twenty years as a student and marketing professor at Harvard Business School, Dr. Albion made the decision that there...

Mark-André Olivier

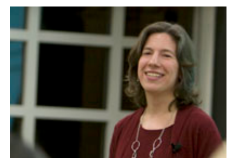
Marc-André has co-developed and co-facilitated the Learning as Leadership curriculum for 15 years. He has studied organizational...

Max Goldberger

In Memoriam: the World Business Academy will miss our dear friend and colleague, Max Goldberger, who passed away in early...

Michael Ray, Ph.D.

Michael L. Ray is the first John G. McCoy-Banc One Corporation Professor of Creativity and Innovation and of Marketing (...



Michelle L. Buck, Ph.D.

Michelle L. Buck is Clinical Associate Professor of Management and Organizations at the Kellogg School of Management at ...

N. Mohan Reddy, Ph.D.

Dr. N. Mohan Reddy is Albert J. Weatherhead III Professor of Management at the Weatherhead School of Management, Case Western...

Patrick K. Takahashi, Ph.D.

Patrick Kengi Takahashi, Ph.D., is the Director Emeritus of the University of Hawaii Natural Energy Institute, and co-founder...

Paul H. Ray, Ph.D.

Dr. Ray was educated at Yale and the University of Michigan, where he was also an associate professor. He is the co-author...

Peter Hoffmann

Peter Hoffmann is the editor of The Hydrogen & Fuel Cell Letter, the voice of the international hydrogen community, ...

Peter Russell

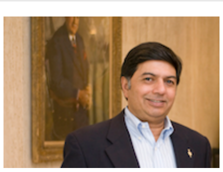
Peter Russell is a fellow of the Institute of Noetic Sciences, of The World Business Academy and of The Findhorn Foundation...

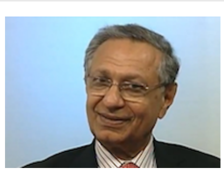
Peter Senge, Ph.D.

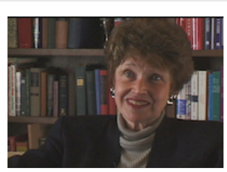
Peter M. Senge is a Senior Lecturer at the Massachusetts Institute of Technology. He is also Chairperson of the Society ...

Philip and Mikela Tarlow

Mikela and Philip Tarlow are leading the call for a psychological futurism: a way of envisioning the road ahead that takes...







Rabbi Michael Lerner, Ph.D.

Rabbi Michael Lerner, Ph.D., is a leading author, public intellectual, and spiritual leader. He is the Editor of Tikkun...

Rajendra S. Sisodia, Ph.D.

Rajendra S. Sisodia, Ph.D., is Professor of Marketing at Bentley University, and was previously Trustee Professor of Marketing...

Ravi Chaudhry

Ravi Chaudhry is a business strategy consultant, mentor to CEOs and corporate Boards, a public intellectual and an author...

Riane Eisler, Ph.D.

Riane Eisler is the author of The Chalice and The Blade: Our History, Our Future in which she introduces the cultural transformation...

Richard Barrett

Richard Barrett's personal mission is threefold...

Richard Tarnas, Ph.D.

Richard Tarnas, Ph.D., is professor of philosophy and psychology at the California Institute of Integral Studies in San ...

Robert M. Fulmer, Ph.D.

Robert M. Fulmer is currently academic director for Duke Corporate Education and Professor Emeritus at the College of William...

Robert Quinn

Robert E. Quinn holds the M.E. Tracy Collegiate Professorship and is a Professor of Organizational Behavior and Human Resource...

Rosabeth Moss Kanter, Ph.D.

Rosabeth Moss Kanter holds the Ernest L. Arbuckle Professorship at Harvard Business School, where she specializes in strategy...

Ruben Nelson

Ruben Nelson has been fascinated by the future for over 40 years. Today, he is committed to understanding societal change...

Stuart L. Hart, Ph.D.

Stuart is the S.C. Johnson Chair of Sustainable Global Enterprise and professor of management at Cornell University's Johnson...

Terry Mollner

Terry Mollner is one of the pioneers of socially responsible investing as a new asset class in the professional investment...

Thomas M. Rau, M.D.

Dr. Rau has been associated with the world's foremost clinic for holistic medicine and dentistry, designed to create individual...

Verna Allee

Verna Allee is an internationally recognized thought leader and author in knowledge management, intangibles and new business...

Wally Amos

Born in Tallahassee, Florida, Wally Amos lived a childhood that was not always stable and trouble free. But as a child he...

Warren Bennis, Ph.D.

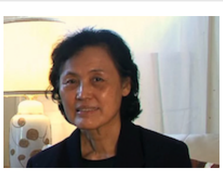
Warren Bennis Ph.D. is University Professor and Distinguished Professor of Business Administration at the University of ...

William Mcdonough FAIA

William McDonough is an internationally respected designer and one of the primary proponents and shapers of what he calls ...

Windeagle and rainbowhawk Kinney-Linton

WindEagle and RainbowHawk, twin Keepers of the Origin Teachings of the Delicate Lodge, carry an ancient body of self-knowledge...



Zhouying Jin, Ph.D.

Professor Zhouying Jin is a senior researcher and professor at the Chinese Academy of Social Sciences(CASS) where she is...

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Review

Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature

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Abstract: We assess climate impacts of global warming using ongoing observations and paleoclimate data. We use Earth's measured energy imbalance, paleoclimate data, and simple representations of the global carbon cycle and temperature to define emission reductions needed to stabilize climate and avoid potentially disastrous impacts on today's young people, future generations, and nature. A cumulative industrial-era limit of ~500 GtC fossil fuel emissions and 100 GtC storage in the biosphere and soil would keep climate close to the Holocene range to which humanity and other species are adapted. Cumulative emissions of ~1000 GtC, sometimes associated with 2°C global warming, would spur "slow" feedbacks and eventual warming of 3–4°C with disastrous consequences. Rapid emissions reduction is required to restore Earth's energy balance and avoid ocean heat uptake that would practically guarantee irreversible effects. Continuation of high fossil fuel emissions, given current knowledge of the consequences, would be an act of extraordinary witting intergenerational injustice. Responsible policymaking requires a rising price on carbon emissions that would preclude emissions from most remaining coal and unconventional fossil fuels and phase down emissions from conventional fossil fuels.

Introduction

Humans are now the main cause of changes of Earth's atmospheric composition and thus the drive for future climate change [1]. The principal climate forcing, defined as an imposed change of planetary energy balance [1–2], is increasing carbon dioxide (CO_2) from fossil fuel emissions, much of which will remain in the atmosphere for millennia [1,3]. The climate response to this forcing and society's response to climate change are complicated by the system's inertia, mainly due to the ocean and the ice sheets on Greenland and Antarctica together with the long residence time of fossil fuel carbon in the climate system. The inertia causes climate to appear to respond slowly to this human-made forcing, but further long-lasting responses can be locked in.

More than 170 nations have agreed on the need to limit fossil fuel emissions to avoid dangerous human-made climate change, as formalized in the 1992 Framework Convention on Climate Change [6]. However, the stark reality is that global emissions have accelerated (Fig. 1) and new efforts are underway to massively expand fossil fuel extraction [7–9] by drilling to increasing ocean depths and into the Arctic, squeezing oil from tar sands and tar shale, hydro-fracking to expand extraction of natural gas, developing exploitation of methane hydrates, and mining of coal via mountaintop removal and mechanized long-wall mining. The growth rate of fossil fuel emissions increased from 1.5%/year during 1980–2000 to 3%/year in 2000–2012, mainly because of increased coal use [4–5].

The Framework Convention [6] does not define a dangerous level for global warming or an emissions limit for fossil fuels. The

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An addendum to the Statement on Climate Change: Evidence from the Geological Record

December 2013

To find out more, visit **www.geolsoc.org.uk/climatechange** or email **policy@geolsoc.org.uk**

Climate change

An addendum to the Geological Society Statement on Climate Change: Evidence from the Geological Record

The Geological Society
serving science & profession

The Geological Society published a Statement on 'Climate Change: Evidence from the Geological Record' in November 2010. In light of further research that has been published since then, the Geological Society reconvened the expert working group that drafted the 2010 Climate Change Statement to consider whether it was still fit for purpose, and if necessary to amend or add to it.

The working group and Council have concluded that the 2010 Climate Change Statement continues to be valid, and does not need to be amended. Instead, the working group has produced an addendum setting out new research findings relevant to the questions raised in the original statement.

A non-technical summary of the key points from the addendum is set out below, aimed principally at non-specialists and Fellows of the Society with a general interest. This is followed by the full technical version of the addendum, for those who wish to read in more detail about advances in the relevant research. The full technical version includes references to the published papers on which it draws. It is intended to be read alongside the original 2010 Climate Change Statement, and follows the same Q&A format.

Summary

Since our original 2010 statement, new climate data from the geological record have arisen which strengthen the statement's original conclusion that CO_2 is a major modifier of the climate system, and that human activities are responsible for recent warming.

Palaeoclimate records are now being used widely to test the validity of computer climate models used to predict climate change. Palaeoclimate models can simulate the large-scale gradients of past change, but tend not to accurately reproduce fine-scale spatial patterns. They also have a tendency to underestimate the magnitude of past changes. Nevertheless they are proving to be increasingly useful tools to aid thinking about the nature and extent of past change, by providing a global picture where palaeoclimate data are geographically limited.

Geologists have recently contributed to improved estimates of climate sensitivity (defined as the increase in global mean temperature resulting from a doubling in atmospheric CO_2 levels). Studies of the Last Glacial Maximum (about 20,000 years ago) suggest that the climate sensitivity, based on rapidly acting factors like snow melt, ice melt and the behaviour of clouds and water vapour, lies in the range 1.5°C to 6.4°C. Recent research has given rise to the concept of 'Earth System sensitivity', which also takes account of slow acting factors like the decay of large ice sheets and the operation of the full carbon cycle, to estimate the full sensitivity of the Earth System to a doubling of CO_2. It is estimated that this could be double the climate sensitivity.

SPM

- A lower warming target, or a higher likelihood of remaining below a specific warming target, will require lower cumulative CO_2 emissions. Accounting for warming effects of increases in non-CO_2 greenhouse gases, reductions in aerosols, or the release of greenhouse gases from permafrost will also lower the cumulative CO_2 emissions for a specific warming target (see Figure SPM.10). {12.5}

- A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Due to the long time scales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40% of emitted CO_2 will remain in the atmosphere longer than 1,000 years. {Box 6.1, 12.4, 12.5}

- It is *virtually certain* that global mean sea level rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries. The few available model results that go beyond 2100 indicate global mean sea level rise above the pre-industrial level by 2300 to be less than 1 m for a radiative forcing that corresponds to CO_2 concentrations that peak and decline and remain below 500 ppm, as in the scenario RCP2.6. For a radiative forcing that corresponds to a CO_2 concentration that is above 700 ppm but below 1500 ppm, as in the scenario RCP8.5, the projected rise is 1 m to more than 3 m (*medium confidence*). {13.5}

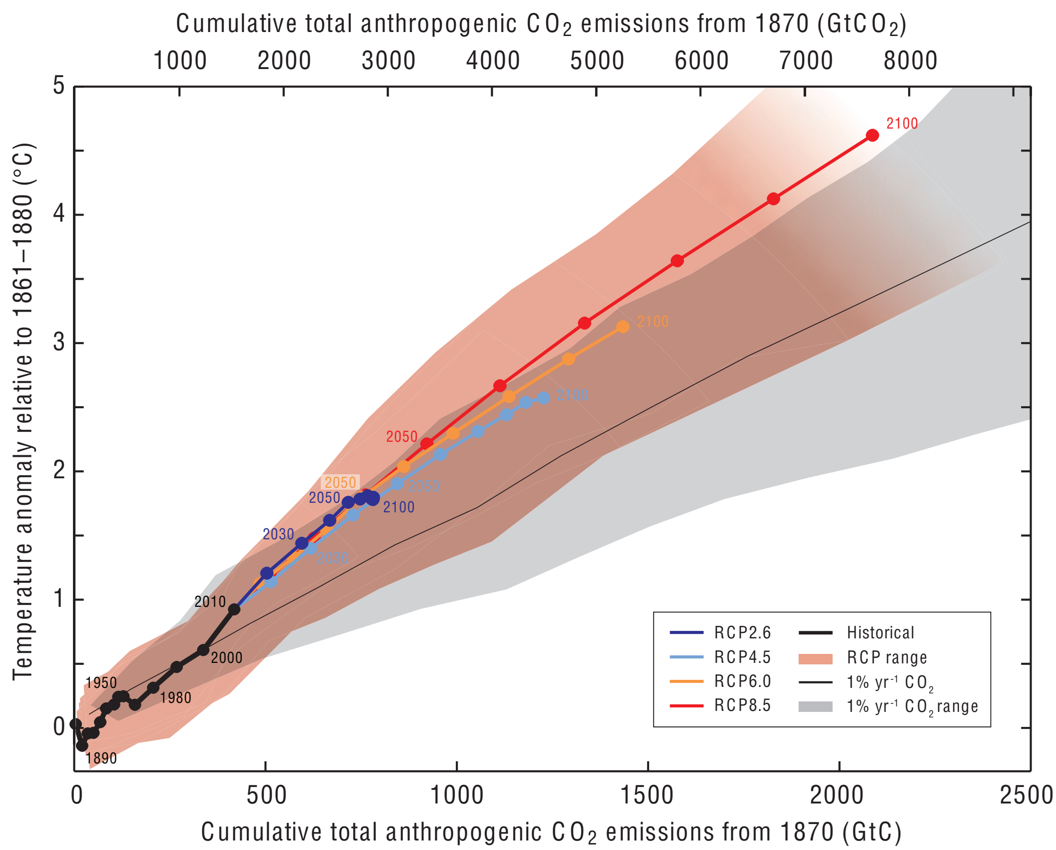

Figure SPM.10 | Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multi-model results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown with coloured lines and decadal means (dots). Some decadal means are labeled for clarity (e.g., 2050 indicating the decade 2040–2049). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. The multi-model mean and range simulated by CMIP5 models, forced by a CO_2 increase of 1% per year (1% yr^{-1} CO_2 simulations), is given by the thin black line and grey area. For a specific amount of cumulative CO_2 emissions, the 1% per year CO_2 simulations exhibit lower warming than those driven by RCPs, which include additional non-CO_2 forcings. Temperature values are given relative to the 1861–1880 base period, emissions relative to 1870. Decadal averages are connected by straight lines. For further technical details see the Technical Summary Supplementary Material. {Figure 12.45; TS TFE.8, Figure 1}

- Sustained mass loss by ice sheets would cause larger sea level rise, and some part of the mass loss might be irreversible. There is *high confidence* that sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m. Current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) global mean warming with respect to pre-industrial. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment. {5.8, 13.4, 13.5}

- Methods that aim to deliberately alter the climate system to counter climate change, termed geoengineering, have been proposed. Limited evidence precludes a comprehensive quantitative assessment of both Solar Radiation Management (SRM) and Carbon D ioxide Removal (CDR) and their impact on the climate system. CDR methods have biogeochemical and technological limitations to their potential on a global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. Modelling indicates that SRM methods, if realizable, have the potential to substantially offset a global temperature rise, but they would also modify the global water cycle, and would not reduce ocean acidification. If SRM were terminated for any reason, there is *high confidence* that global surface temperatures would rise very rapidly to values consistent with the greenhouse gas forcing. CDR and SRM methods carry side effects and long-term consequences on a global scale. {6.5, 7.7}

Box SPM.1: Representative Concentration Pathways (RCPs)

Climate change projections in IPCC Working Group I require information about future emissions or concentrations of greenhouse gases, aerosols and other climate drivers. This information is often expressed as a scenario of human activities, which are not assessed in this report. Scenarios used in Working Group I have focused on anthropogenic emissions and do not include changes in natural drivers such as solar or volcanic forcing or natural emissions, for example, of CH_4 and N_2O.

For the Fifth Assessment Report of IPCC, the scientific community has defined a set of four new scenarios, denoted Representative Concentration Pathways (RCPs, see Glossary). They are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 W m^{-2} for RCP2.6, 4.5 W m^{-2} for RCP4.5, 6.0 W m^{-2} for RCP6.0, and 8.5 W m^{-2} for RCP8.5. For the Coupled Model Intercomparison Project Phase 5 (CMIP5) results, these values should be understood as indicative only, as the climate forcing resulting from all drivers varies between models due to specific model characteristics and treatment of short-lived climate forcers. These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5). The RCPs can thus represent a range of 21st century climate policies, as compared with the no-climate policy of the Special Report on Emissions Scenarios (SRES) used in the Third Assessment Report and the Fourth Assessment Report. For RCP6.0 and RCP8.5, radiative forcing does not peak by year 2100; for RCP2.6 it peaks and declines; and for RCP4.5 it stabilizes by 2100. Each RCP provides spatially resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2100. RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models. While the RCPs span a wide range of total forcing values, they do not cover the full range of emissions in the literature, particularly for aerosols.

Most of the CMIP5 and Earth System Model simulations were performed with prescribed CO_2 concentrations reaching 421 ppm (RCP2.6), 538 ppm (RCP4.5), 670 ppm (RCP6.0), and 936 ppm (RCP 8.5) by the year 2100. Including also the prescribed concentrations of CH_4 and N_2O, the combined CO_2-equivalent concentrations are 475 ppm (RCP2.6), 630 ppm (RCP4.5), 800 ppm (RCP6.0), and 1313 ppm (RCP8.5). For RCP8.5, additional CMIP5 Earth System Model simulations are performed with prescribed CO_2 emissions as provided by the integrated assessment models. For all RCPs, additional calculations were made with updated atmospheric chemistry data and models (including the Atmospheric Chemistry and Climate component of CMIP5) using the RCP prescribed emissions of the chemically reactive gases (CH_4, N_2O, HFCs, NO_x, CO, NMVOC). These simulations enable investigation of uncertainties related to carbon cycle feedbacks and atmospheric chemistry.

Top climate change scientists' letter to policy influencers

updated 8:12 AM EST, Sun November 3, 2013

CNN.com

"... there is no credible path to climate stabilization that does not include a substantial role for nuclear power," the letter says.

Editor's note: *Climate and energy scientists James Hansen, Ken Caldeira, Kerry Emanuel and Tom Wigley released an open letter Sunday calling on world leaders to support development of safer nuclear power systems. For more on the future of nuclear power as a possible solution for global climate change, watch CNN Films' presentation of "Pandora's Promise," Thursday, November 7, at 9 p.m. ET/PT.*

(CNN) -- To those influencing environmental policy but opposed to nuclear power:

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

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

Read more about the letter and the controversy surrounding it

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

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

Quantitative analyses show that the risks associated with the expanded use of nuclear energy are orders of magnitude smaller than the risks associated with fossil fuels. No energy system is without downsides. We ask only that energy system decisions be based on facts, and not on emotions and biases that do not apply to 21st century nuclear technology.

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

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

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

Sincerely,

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January 6, 2014

Gentlemen,

Although we greatly respect your work on climate and lending it a much higher profile in public dialogue than would otherwise be the case, we read your letter of November 3, 2013 urging the environmental community to support nuclear power as a solution to climate change with concern. We respectfully disagree with your analysis that nuclear power can safely and affordably mitigate climate change.

Nuclear power is not a financially viable option. Since its inception it has required taxpayer subsidies and publically financed indemnity against accidents. New construction requires billions in public subsidies to attract private capital and, once under construction, severe cost overruns are all but inevitable. As for operational safety, the history of nuclear power plants in the US is fraught with near misses, as documented by the Union of Concerned Scientists, and creates another financial and safety quagmire – high-level nuclear waste. Internationally, we've experienced two catastrophic accidents for a technology deemed to be virtually 'failsafe'.

As for "advanced" nuclear designs endorsed in your letter, they have been tried and failed or are mere blueprints without realistic hope, in the near term, if ever, to be commercialized. The promise and potential impact you lend breeder reactor technology in your letter is misplaced. Globally, $100 billion over sixty years have been squandered to bring the technology to commercialization without success. The liquid sodium-based cooling system is highly dangerous as proven in Japan and the US. And the technology has proven to be highly unreliable.

Equally detrimental in cost and environmental impact is reprocessing of nuclear waste. In France, the poster child for nuclear energy, reprocessing results in a marginal increase in energetic use of uranium while largely increasing the volume of all levels of radioactive waste. Indeed, the process generates large volumes of radioactive liquid waste annually that is dumped into the English Channel and has increased electric costs to consumers significantly. Not to mention the well-recognized proliferation risks of adopting a plutonium-based energy system.

We disagree with your assessment of renewable power and energy efficiency. They can and are being brought to scale globally. Moreover, they can be deployed much more quickly than nuclear power. For instance, in the US from 2002 to 2012 over 50,000 megawatts of wind were deployed. Not one megawatt of power from new nuclear reactors was deployed, despite subsidies estimated to be worth more than the value of the power new reactors would have produced. Similarly, it took 40 years globally to deploy 50,000 megawatts of solar PV and, recently, only 2 ½ years to deploy an equal amount. By some estimates, another 100,000 MW will be built by the end of 2015. Already, renewables and distributed power have overtaken nuclear power in terms of megawatt hour generation worldwide.

The fact of the matter is, many Wall Street analysts predict that solar PV and wind will have reached grid parity by the end of the decade. Wind in certain parts of the Midwest is already cheaper than natural gas on the wholesale level. Energy efficiency continues to outperform all technologies on a cost basis. While the cost of these technologies continues to decline and enjoy further technological advancement, the cost of nuclear power continues to increase and construction timeframes remain excessive. And we emphasize again that no technological breakthrough to reduce its costs or enhance its operation will occur in the foreseeable future.

Moreover, due to the glacial pace of deployment, the absence of any possibility of strategic technological breakthroughs, and the necessity, as you correctly say, of mitigating climate risks in the near term, nuclear technology is ill-suited to provide any real impact on greenhouse gas emissions in that timeframe. On the contrary, the technologies perfectly positioned now, due to their cost and level of commercialization, to attain decisive reductions in greenhouse gas emissions in the near term are renewable, energy efficiency, distributed power, demand response, and storage technologies.

Instead of embracing nuclear power, we request that you join us in supporting an electric grid dominated by energy efficiency, renewable, distributed power and storage technologies. We ask you to join us in supporting the phase-out of nuclear power as Germany and other countries are pursuing.

It is simply not feasible for nuclear power to be a part of a sustainable, safe and affordable future for humankind.

We would be pleased to meet with you directly to further discuss these issues, to bring the relevant research on renewable energy and grid integration to a dialog with you. Again, we thank you for your service and contribution to our country's understanding about climate change.

The energy choices we make going forward must also take into account the financial, air and water impacts and public health and safety. There are alternatives to fossil fuels and nuclear power and we welcome a chance to a dialog and debate with each of you.

Sincerely,

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An unexpected rise in strontium-90 in US deciduous teeth in the 1990s

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Abstract

For several decades, the United States has been without an ongoing program measuring levels of fission products in the body. Strontium-90 (Sr-90) concentrations in 2089 deciduous (baby) teeth, mostly from persons living near nuclear power reactors, reveal that average levels rose 48.5% for persons born in the late 1990s compared to those born in the late 1980s. This trend represents the first sustained increase since the early 1960s, before atmospheric weapons tests were banned. The trend was consistent for each of the five states for which at least 130 teeth are available. The highest averages were found in southeastern Pennsylvania, and the lowest in California (San Francisco and Sacramento), neither of which is near an operating nuclear reactor. In each state studied, the average Sr-90 concentration is highest in counties situated closest to nuclear reactors. It is likely that, 40 years after large-scale atmospheric atomic bomb tests ended, much of the current in-body radioactivity represents nuclear reactor emissions.

Keywords: Radiation; Strontium-90; Nuclear reactors; Deciduous teeth (baby teeth)

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1. Introduction

Since man-made fission products were first released into the environment in the mid-1940s, determining in vivo levels of these radioisotopes has challenged scientists. Hundreds of radioisotopes are created in nuclear weapon detonations and in nuclear reactor emissions. Many of these are short-lived, and therefore highly unlikely to track in vivo. Collecting samples of longer-lived isotopes often involves invasive processes such as autopsies and biopsies, making collection of significant samples time-consuming and costly.

In the US, whose government conducted 206 atmospheric tests of nuclear weapons from 1946 to 1962 (100 in Nevada, 106 in the South Pacific) (Norris and Cochran, 1994), the federal government instituted programs measuring strontium-90 (Sr-90) concentrations in vertebrae. One focused on deceased adults (begun 1954, 3 cities, ~50 bones per year) (Klusek, 1984), while the other included deceased children and adolescents (begun 1962, 30 cities, ~300 bones per year) (Baratta et al., 1970). Both showed increases to a peak in 1964, just after the Partial Test Ban Treaty was signed, and a dramatic decline in the mid- and late 1960s.

The largest-scale US program studying in-body radioactivity was conducted in St. Louis. Kalckar suggested that large numbers of deciduous teeth could be collected and tested to examine the buildup of fallout from bomb tests (Kalckar, 1958). A coalition of St. Louis medical/scientific professionals and citizens collected over 300 000 teeth from local children from 1958 to 1970. Results from St. Louis were similar to the two bone programs, i.e.

- A 55-fold rise in average millibecquerels (mBq) of Sr-90 per gram calcium at birth (7.4–408.1) took place for 1949–1950 births (before large-scale tests began) to 1964 births (just after the largest-scale bomb tests ended).
- A 50% decline in Sr-90 concentrations in St. Louis fetal mandibles occurred from 1964 to 1969 births. This far exceeded the expected 9% reduction suggested by the 28.7 year half-life of Sr-90 (Rosenthal, 1969).

After the bone and tooth studies showed such a rapid post-1964 decline, federal funding was terminated for each program, and work ceased. The tooth study ended in 1970, the child bone study in 1971 and the adult bone study in 1982.

The US studies were accompanied by similar international efforts. Each independently confirmed the American findings of rapid increases in teeth until 1964, including studies in Czechoslovakia, Denmark, Finland and Scotland (Santholzer and Knaifl, 1966; Aarkrog, 1968; Rytomaa, 1972; Fracassini, 2002). Another study in Finland duplicated the rapid post-1964 plunge in Sr-90 (Kohlehmainen and Rytomaa, 1975). No nation maintained an ongoing program, but after the Chernobyl accident, reports from Germany, the Ukraine and Greece documented a substantial rise in Sr-90 in baby teeth after the April 1986 disaster (Scholz, 1996; Kulev et al., 1994; Stamoulis et al., 1999). Another study examined Sr-90 in teeth from children who lived proximate to the Sellafield nuclear installation in northwestern England; results are addressed in Section 4 (O'Donnell et al., 1997).

With no program of in vivo radioactivity to gauge the burden on the body, levels in the environment can be used as a proxy measure. In the past, patterns of Sr-90 in baby teeth were roughly equivalent to those of Sr-90 in milk (Rosenthal et al., 1964). The US government (beginning 1957) began publicly reporting monthly levels of a variety of radionuclides in milk and water in 40–60 US locations. However, a number of these radioisotopes, including Sr-90, strontium-89, cesium-137, barium-140 and iodine-131 were discontinued in the early 1990s (National Air and Radiation Environmental Laboratory, 1975–2001).

One measure that is still publicly reported is the concentration of gross beta particles in precipitation. A reduction in average beta levels reversed after 1986–1989. While the most recent 4-year period still features incomplete data, thus far the increase from 1986–1989 to 1998–2001 has been 53.8%. This difference is significant at $P<0.0001$,

Table 1
Trend in gross beta in precipitation in average millibecquerels per liter of water in 60 US cities, 1978–2001

4-year period	Months available	Number of measurements	Average beta[a]	Percent change, 1986–1989 to 1998–2001[b]
1978–1981	36	640	211	
1982–1985	48	1299	63	
1986–1989	46[c]	1845	58	
1990–1993	48	1892	59	
1994–1997	48	1696	63	
1998–2001	27	836	89	+53.8% ($P<0.0001$)

The P value indicates that the chance that the increase is due to random chance is fewer than 1 in 10 000. *Source:* Environmental Protection Agency, Environmental Radiation Data, quarterly volumes.

[a] Average millibecquerels of gross beta per liter of precipitation (reported by EPA as picocuries; to convert to millibecquerels, multiply by 37). Before 1996, figures were reported as nanocuries per meter squared at a particular depth (in millimeters); to convert to pCi/l, multiply nCi per meter squared times 1000, then divide by millimeters; then multiply by 37 to obtain millibecquerels.

[b] Calculation of change beginning with lowest average (1986–1989) to most current.

[c] Excludes May and June 1986, heavily affected by short-lived Chernobyl fallout.

i.e. the probability of this increase due to random chance is less than 1 in 10 000 (Table 1).

The lack of an ongoing program measuring in vivo radioactivity levels and an unexpected, sustained rise in environmental beta concentrations warrant a resumption of testing in vivo Sr-90 and perhaps other radioisotopes, first instituted during the era of atmospheric nuclear weapons testing.

In 1996, the Radiation and Public Health Project (RPHP) began a study of Sr-90 levels in deciduous teeth, focused on persons living near nuclear reactors. The goal of this project was to build a current database of in vivo radioactivity documenting Sr-90 patterns and trends. While Sr-90 is just one of hundreds of radioisotopes from fission, it can be used as a proxy for all fission products, especially those with extended half-lives.

2. Materials and methods

Earlier reports addressed methods used and initial findings from the baby tooth study (Gould et al., 2000a,b; Mangano et al., 2000). These teeth were processed using a scintillation counter from the University of Waterloo in Ontario, Canada. In June of 2000, RPHP leased a Perkin-Elmer 1220-003 Quantulus Ultra Low-Level Liquid Scintillation Spectrometer. Introduced in 1995, only approximately 15–20 units are now in use in the US (Laxton, Mark, Perkin-Elmer Life Sciences Inc., 549 Albany Street, Boston MA 02118. Personal correspondence, May 9, 2002).

The new counter is located on the premises of REMS, Inc., a radiochemistry laboratory in Waterloo, and not at the University of Waterloo, thus changing the level of background radiation. Also, the method of removing organic material from the teeth was changed by treating them with hydrogen peroxide prior to grinding them into powder. This procedure proved to be more effective in allowing light produced in the liquid scintillation fluid by the beta particles emitted by the Sr-90 and its daughter product, Yttrium-90, to reach the photomultipliers. This greater efficiency is caused partly by shifting the spectrum of the light emitted by the scintillation fluid. As a result of these changes (the counter, its location, level of background radiation and method of cleaning teeth), the efficiency of detecting the very low radioactivity in single teeth was more than doubled overall. However, the data lack a consistent factor that could be used to analyze teeth from both counters together. Thus, this report will be based solely on the 2089 deciduous teeth tested after June 2000.

RPHP sends teeth to REMS for testing, and Sr-90 levels are measured individually. Lab personnel are blinded about all information concerning each tooth, that is, they know nothing about character-

Table 2
Average millibecquerels of Sr-90 per gram calcium (at birth) in deciduous teeth from St. Louis, 1954 and 1959 births (test for internal consistency)

Batch		Average Sr-90[a]	% 1959 over 1954	Counting error	95% confidence interval
#1	1954	61		±10	41–81
	1959	121	+98	±13	95–147
#2	1954	65		±11	43–87
	1959	124	+90	±14	96–152

[a] Average millibecquerels of Sr-90 per gram of calcium.

istics of the tooth donor. This blinding helps assure objectivity in results. The laboratory measures the concentration of Sr-90 by calculating the current activity (in mBq) of Sr-90 per gram of calcium in each tooth (mBq Sr-90/g Ca). (See Appendix A for more specific technical procedures.) The strontium-to-calcium ratio has been used in the St. Louis study in the 1960s, and all other recent baby tooth studies mentioned earlier.

The laboratory returns results to RPHP staff, who converts the ratio to that at birth, using the Sr-90 half-life of 28.7 years. The Sr-90/Ca ratio for a single tooth is not a precise number because a typical baby tooth is small in mass. The counting error for each tooth is plus or minus 26 mBq, and somewhat less for the larger teeth.

RPHP conducted several tests to assure the inter-laboratory reliability and internal consistency of its results. It selected 10 teeth from persons born in 1954 in St. Louis that were tested both by REMS and the University of Georgia Center for Applied Isotope Studies, which operates three counters of the same model. REMS dried the 10 teeth and ground them into a powder. After testing for Sr-90 levels, the entire batch was sent to the University of Georgia, which tested a dissolved solution of teeth. Both labs were blinded from each other's results. The data were relatively comparable. REMS' average was 65 mBq Sr-90/g Ca (CI=43–87), while University of Georgia's tally was 79 mBq/g Ca (CI=56–102).

REMS also performed a second test, for internal consistency. Prior results from the St. Louis study indicated that average 1959 Sr-90 levels were considerably higher than those for 1954, due to buildup in bomb test fallout. RPHP split two samples of 10 teeth, each into two batches, and asked REMS to calculate average Sr-90 levels separately. Results, shown in Table 2, documented the 1959 average to be 98 and 90% higher than the 1954 average. Confidence intervals showed considerable overlap, indicating that study results are consistent both internally and with the earlier St. Louis study.

A third test for accuracy involved several dozen teeth from persons born in the Philippines Islands 1991–1992. This area has never had a nuclear reactor (for weapons, power or research). It may have received fallout from Chinese atmospheric bomb tests, but there were many fewer of these than US tests. Chinese atmospheric tests ended in 1980, and the last below-ground test occurred in 1993. Thus, Philippino teeth should contain lower concentrations of this radioisotope than American teeth.

Thirteen teeth of Philippino children born in 1991 and 1992 were tested. The average concentration at birth was 75 mBq Sr-90/g Ca, or 41% lower than the 127 mean level for American children born in those years.

RPHP collects teeth through voluntary donations, mostly from parents of children who have recently shed a deciduous tooth. Donors submit teeth in envelopes containing identifying information on the child and parents. RPHP staff assigns each tooth a unique tracking number. The group sent nearly 100 000 unsolicited letters appealing for tooth donation to families with children age 6–17. These mailings occurred in California (Sacramento and San Luis Obispo counties), Florida (Dade and Port St. Lucie counties) and New York (Rockland and Westchester counties). Families

Table 3
Average millibecquerels of Sr-90 per gram calcium in deciduous teeth (at birth) by state (all persons and persons born after 1979)

State	Teeth	Average Sr-90[a]	Counting error
All persons			
PA	133	155	±14
Oth	492	146	±7
NY	557	141	±6
NJ	271	139	±9
FL	485	131	±6
CA	151	114	±10
TOT	2089	139	±3
Persons born after 1979			
PA	130	154	±14
NY	534	138	±6
FL	471	130	±6
Oth	417	130	±6
NJ	244	125	±8
CA	138	108	±10
TOT	1934	132	±3

See Appendix B for explanation of error calculation.
[a] Average millibecquerels of Sr-90 per gram of calcium.

receiving letters were randomly selected by zip code in each county, that is, every *n*th family in each zip code received a letter. Just over 1% of these mailings were returned with a baby tooth enclosed.

Teeth are geographically classified by the zip code where the mother resided during pregnancy, rather than the current residence. The large majority of Sr-90 uptake in a baby tooth occurs during the fetal and early infant periods (Rosenthal, 1969), making zip code during pregnancy the appropriate geographic identifier.

Other teeth were collected from persons who became familiar with the project through media articles and stories, and through the group's web site. Thus, the teeth are not necessarily representative of the US population at large. The vast majority is concentrated in only five states (California, Florida, New Jersey, New York and Pennsylvania), near nuclear reactors. Most were donated from children who have just recently lost a tooth, or those between age 5 and 13. Despite these shortcomings, the large number of teeth will enable meaningful analysis of average Sr-90 concentrations to be performed; and any major variations—by birth year, by state, etc.—will likely be discernible.

3. Results

3.1. By state

A total of 2089 teeth were tested for Sr-90, and are discussed in this paper (another 1335 had been tested previously using a different scintillation counter and method). As discussed, the two sets of results are each internally consistent, but not comparable with each other because of differences in the counter, its location, level of background radiation and method of cleaning teeth, so only the last 2089 teeth are used. Of these, 1592 (77%) were from children born in the five states mentioned earlier, each with at least 133 teeth studied. No other state has more than 34 teeth. Table 3 shows the comparative average Sr-90 concentrations by state.

Table 3 also displays averages by state only for persons born after 1979. The large buildup from above-ground nuclear weapons tests reached a peak in 1964, and fell by approximately half over

Table 4
Average millibecquerels of Sr-90 per gram calcium in deciduous teeth (at birth) by proximity to nuclear power plants (persons born after 1979)

Nuclear power plant, location	Proximate counties	Average Sr-90[a] (No. teeth)		% Difference average Sr-90
		Proximate	Other state	
Indian Point, Buchanan NY (2 reactors, startup 1973, 1976)	Putnam, Rockland, Westchester, NY	164 (217) ±11	121 (317) ±7	+35.8% $P<0.001$
Limerick, Pottstown PA (2 reactors, startup 1984, 1989)	Berks, Chester, Montgomery, PA	168 (98)[b] ±17	110 (32) ±20	+53.2% $P<0.03$
Turkey Point, Florida City FL (2 reactors, startup 1972, 1973)	Broward, Dade, Palm Beach, FL	129 (350) ±7	93 (24) ±20	+38.6% $P<0.08$
St. Lucie, Hutchinson Island FL (2 reactors, startup 1976, 1983)	Indian River, Martin, St. Lucie, FL	143 (97) ±15	93 (24) ±20	+53.8% $P<0.04$
Oyster Creek, Forked River NJ (1 reactor, startup 1969)	Monmouth, Ocean, NJ	128 (169) ±10	119 (75) ±14	+8.1%
Diablo Canyon, Avila Beach CA (2 reactors, startup 1984, 1985)	San Luis Obispo, Santa Barbara, CA	127 (50)[b] ±19	97 (88) ±11	+30.8%

Counting error listed for each sample of teeth. See Appendix B for explanation of standard error calculation, Appendix C for significance testing. *Source:* US Nuclear Regulatory Commission (www.nrc.gov), obtained August 12, 1999, for reactor locations and startup dates.

[a] Average millibecquerels of Sr-90 per gram of calcium.

[b] In three counties near Limerick, 94 of 98 teeth were from persons born after startup (average 168). In two counties near Diablo Canyon, 47 of 50 teeth were from persons born after startup (average 135).

the next 5 years. Thus, continued decline of Sr-90 from bomb test fallout should have reached a level approaching zero by about 1980, and averages should largely represent current sources of this radionuclide. Average Sr-90 concentration for all teeth was 132 mBq Sr-90/g Ca, and state averages ranged from a high of 154 in Pennsylvania to a low of 108 in California.

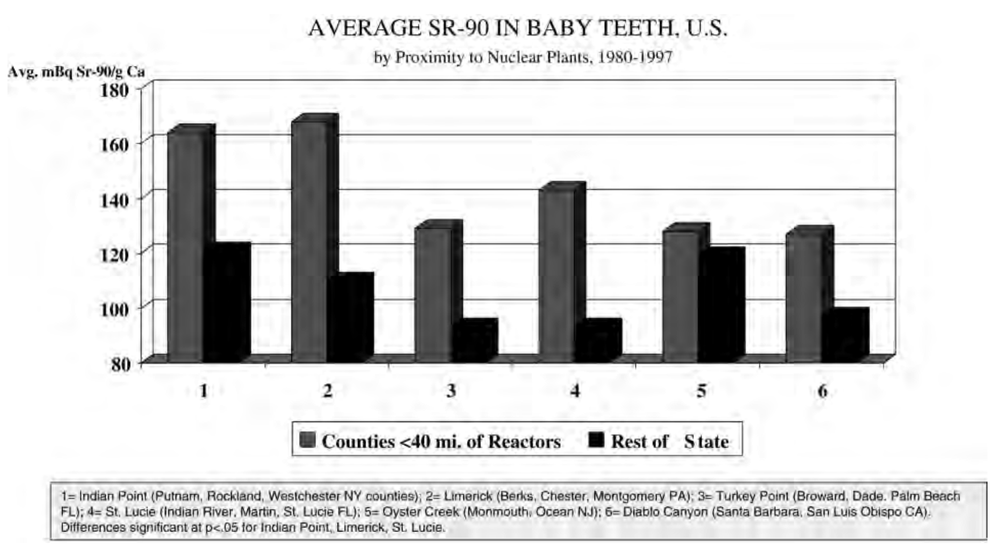

Fig. 1. Average Sr-90 in baby teeth, US, by proximity to nuclear plants (persons born 1980–1997).

Table 5
Average Sr-90 concentration (by birth year), US, in deciduous teeth (at birth)

Birth year	No. teeth	Average Sr-90[a]	Counting error
1954–1957	6	191	±78
1958–1961	8	331	±117
1962–1965	8	351	±124
1966–1969	17	272	±66
1970–1973	38	222	±36
1974–1977	38	211	±34
1978–1981	78	140	±16
1982–1985	172	140	±11
1986–1989	532	109	±5
1990–1993	836	132	±5
1994–1997	346	162	±9
% Change, 1986–1989 to 1994–1997			+48.5% $P<0.0001$

Note: Most teeth are from states of CA, FL, NJ, NY and PA. See Appendix B for explanation of error calculation, Appendix C for significance testing.
[a] Average millibecquerels of Sr-90 per gram of calcium.

3.2. By proximity to nuclear reactors

The question of whether those living closest to nuclear plants have higher burdens of radioactivity was addressed. Most teeth from residents close to nuclear plants—defined as counties situated mostly or completely within 40 miles—include six nuclear installations, described in Table 4 and Fig. 1. Average Sr-90 concentrations are compared with those from all counties in the remainder of the state, which are farther from reactors.

For each of the six areas, the local average of Sr-90 exceeded that for the remainder of the state. Three of the six differences are significant at $P<0.05$, with one other of borderline significance ($P<0.08$). Aside from a 8.1% excess near the Oyster Creek plant in central New Jersey, average Sr-90 concentrations near the other five reactors ranged from 30.8 to 53.8% above other counties in these states. Two parts of California can be considered relatively unexposed control areas. One is composed of Sacramento and El Dorado, close

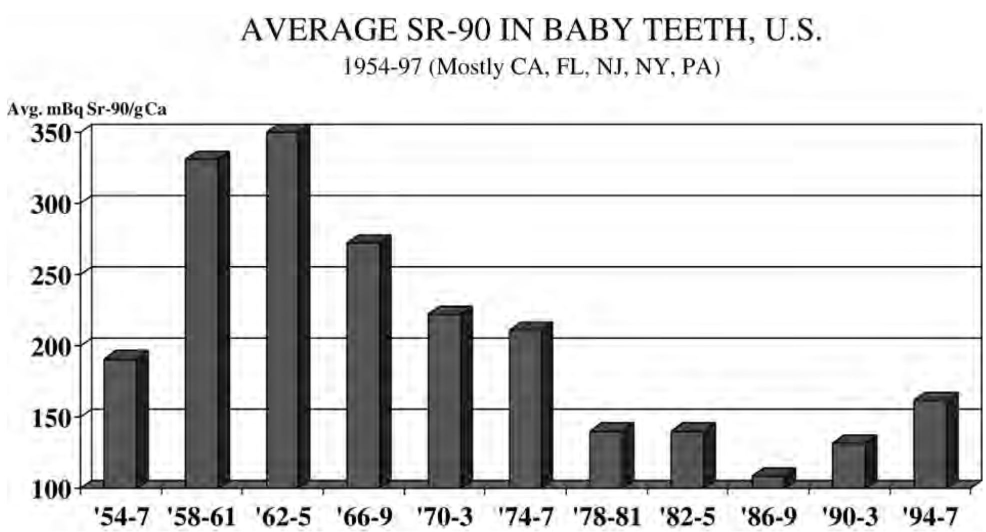

Fig. 2. Average Sr-90 in baby teeth, US, 1954–1997 (mostly CA, FL, NJ, NY, PA).

Table 6
Trend in Sr-90 concentration after 1981 in deciduous teeth, at birth by birth year, by state

Birth year	No. teeth	Average Sr-90[a]/counting error		No. teeth	Average Sr-90[a]/counting error	
California				*Florida*		
1982–1985	12	104	±31	63	133	±17
1986–1989	50	93	±14	102	112	±11
1990–1993	53	112	±16	192	127	± 9
1994–1997	20	139	±32	99	153	±16
% Change 1986–1989 to 1994–1997			+50.2%			+36.3% $P<0.04$
New Jersey				*New York*		
1982–1985	19	117	±27	41	153	±24
1986–1989	71	105	±14	142	120	±10
1990–1993	109	132	±13	237	128	± 9
1994–1997	39	144	±23	104	184	±18
% Change 1986–1989 to 1994–1997			+36.5%			+53.6% $P<0.002$
Pennsylvania				*All other*		
1982–1985	6	293	±120	31	134	±24
1986–1989	32	125	±23	135	100	±9
1990–1993	52	152	±21	193	141	±10
1994–1997	36	160	±27	48	159	±23
% Change 1986–1989 to 1994–1997			+27.7%			+59.0% $P<0.02$

See Appendix B for explanation of error calculation, Appendix C for significance testing.
[a] Average millibecquerels of Sr-90 per gram of calcium.

to the Rancho Seco nuclear plant, which closed in June 1989. The other is the San Francisco Bay area, which lies approximately 80 miles from Rancho Seco and 210 miles from the Diablo Canyon plant. The 50 teeth from persons born after 1979 near Diablo Canyon have the highest Sr-90 concentration in the state (127 mBq/g Ca), followed by those near the closed Rancho Seco plant (106 mBq/g Ca, 27 teeth), and the San Francisco Bay area (87 mBq/g Ca, 23 teeth).

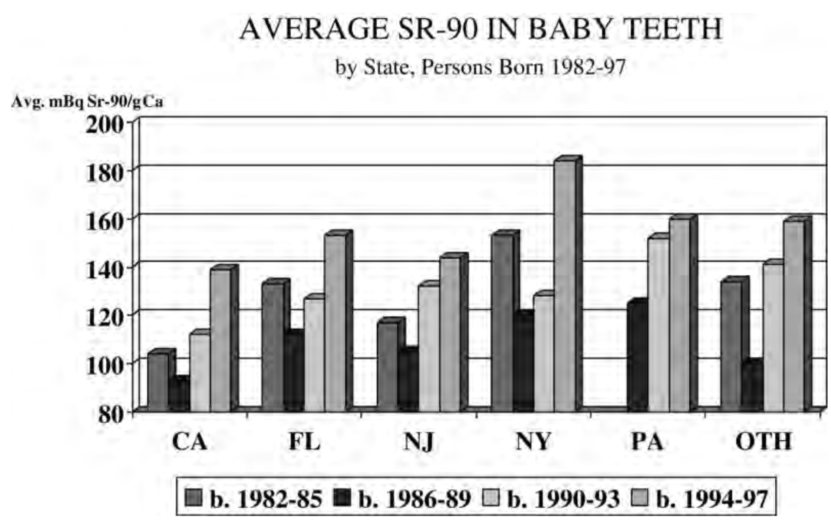

Fig. 3. Average Sr-90 in baby teeth, by state (persons born 1982–1997).

3.3. Temporal trends—total

Temporal trends in average in vivo Sr-90 concentrations were also analyzed. The earlier St. Louis study documented a 50% decline in average Sr-90 concentration in fetal mandibles in the 5 years after the Limited Test Ban Treaty went into effect (Rosenthal, 1969). The adult bone (vertebrae) program administered by the US government showed a similar decline, followed by a more modest reduction since the mid-1970s; this program was small in scope, and ceased in 1982 (Klusek, 1984). The teeth analyzed in this report represent persons born primarily in the 1980s and 1990s, providing data for a population not heretofore addressed.

Table 5 and Fig. 2 display the trend in average Sr-90 concentrations from the mid-1950s to the late 1990s. The trends established by earlier analyses (a rise until the mid-1960s followed by a decline until the early 1980s) were duplicated, even with a limited number of teeth studied prior to 1980. The new findings for those children born after 1981, who contributed 91% of all samples in the study, showed that the decline continued until the period 1986–1989. Four-year birth cohorts are used here to maximize numbers of teeth and smooth trends. In 1986–1989, the lowest average Sr-90 concentration in the study was observed (109 mBq Sr-90/g Ca), well below the 351 mBq Sr-90/g Ca observed in the mid-1960s. This long-term decline was followed by an increase of 48.5% in the next two 4-year periods, ending with an average of 162 mBq Sr-90/g Ca for the 1994–1997 birth cohort ($P<0.0001$). Although trends for individual years are less reliable due to fewer teeth, the lowest average was reached in 1986 (94 mBq Sr-90/g Ca for 76 teeth) and the highest average thereafter occurred in 1996 (195 mBq Sr-90/g Ca for 30 teeth), an increase of 107% ($P<0.007$). Only six teeth for births after 1996 have been analyzed to date.

3.4. Temporal trends—by state

The unexpected and abrupt reversal of declines in Sr-90 concentration in US baby teeth takes on greater meaning when data from each state are analyzed. 'National' data essentially include only five states, and thus may or may not be representative of the entire US. However, for post-1981 births, each of the five states duplicates the same trend; a reduction to a post-Test Ban low in 1986–1989, followed by two successive increases in the following 4-year periods. The geographic disparity of these areas suggests that the trend may apply nation-wide, at least in areas near nuclear reactors, from which most study teeth were donated. Table 6 and Fig. 3 display these consistent trends, which also occurred for the 'all other' categories (teeth from children in areas other than the five focus states). Rises during the 1990s vary from 27.7 to 59.0%. Increases in Florida, New York and 'other' states are significant ($P<0.05$).

3.5. Temporal trends—by counties

The trends in states were also consistent for the counties (or clusters of counties) that donated the most teeth to the study (Table 7). These include Monmouth/Ocean County, NJ (closest to the Oyster Creek plant), Dade County, FL (site of the Turkey Point plant) and Putnam/Rockland/Westchester Counties, NY (which converge at the Indian Point plant). Increases from 1986–1989 to 1994–1997 ranged from 49.8 to 55.7%, with the Florida and New York counties achieving statistical significance ($P<0.05$). The only slight exception to this trend was that all of Monmouth/Ocean County's increase took place in the early 1990s.

4. Discussion

The US has conducted no official program measuring in vivo levels of fission products for over 20 years. This report introduces current data on patterns and trends of Sr-90 concentration in US baby teeth, mostly near nuclear power installations. The average concentration of Sr-90 was 132 mBq Sr-90/g Ca for all children born after 1979, when in vivo Sr-90 remaining from atomic

Table 7
Trend in Sr-90 concentration after 1981 in deciduous teeth (at birth) by birth year, by county (counties with the largest sample sizes)

Birth year	No. teeth	Average Sr-90[a]	Counting error
Dade County FL			
1982–1985	47	141	±21
1986–1989	57	94	±13
1990–1993	106	124	±12
1994–1997	43	141	±22
% Change 1986–1989 to 1994–1997			+50.6% $P<0.057$
Monmouth, Ocean Counties NJ			
1982–1985	13	150	±40
1986–1989	44	93	±14
1990–1993	76	140	±16
1994–1997	31	139	±25
% Change 1986–1989 to 1994–1997			+49.8%
Putnam, Rockland, Westchester Counties NY			
1982–1985	17	202	±50
1986–1989	43	135	±21
1990–1993	101	148	±15
1994–1997	52	211	±30
% Change 1986–1989 to 1994–1997			+55.7% $P<0.04$

See Appendix B for explanation of error calculation, Appendix C for significance testing.
[a] Average millibecquerels of Sr-90 per gram of calcium.

bomb tests should approach 0.[5] This concentration is lower than that in those born before 1980, when bomb test fallout accounted for a substantial proportion of in vivo radioactivity. However, it exceeds the levels before the large-scale testing began in 1951 in Nevada (Rosenthal, 1969).

Long-term declines first slowed in the 1982–1985 period, when no change was observed from the previous 4 years. The reason(s) for this departure is not certain. The decline resumed into the period 1986–1989.

The most dramatic and unexpected finding in this report is the reversal after the late 1980s of decades-long declines in average Sr-90 concentration. We observed a 48.5% higher concentration in 1994–1997 births over 1986–1989 births (162 vs. 109 mBq Sr-90/g Ca), a trend consistent for each of five states (and counties in these states near nuclear reactors) included in this study. This temporal change cannot represent the continued decay of old bomb test fallout from Nevada; rather, it probably represents rising amounts of a currently produced source of environmental radioactivity entering the body. Current sources of Sr-90, a man-made fission product, are limited during the 1990s, and most are not likely to account for recently rising levels of Sr-90 in baby teeth.

(1) Fallout from the 1986 Chernobyl accident (including Sr-90) entered the US environment, raising levels of long-lived radionuclides, but these returned to pre-1986 levels within 3 years (Mangano, 1997; National Air and Radiation Environmental Laboratory, 1975–2001). For example, a rise of 98–311 mBq Cesium-137/l in pasteurized milk occurred in 60 US cities from May–June 1985 to May–June 1986, when Chernobyl fallout levels in the US peaked. This concentration in the same 2-month period in the following years

[5] Stamoulis et al. (1999) contains a chart summarizing trends in Sr-90 in deciduous teeth from various European nations and the Soviet Union. The chart shows that, from a level of approximately 10 mBq/g Ca in 1951, a peak of 250 was reached in 1964, similar to the US trend. By 1975, the average level had fallen to approximately 30 (three times the 1951 average) and was still declining. Three times the 1951 US average of just over 7 means that the 1975 US Sr-90 average should have been approximately 22. But the actual 1975 average found by RPHP was 183 (12 teeth), and 198 for 29 teeth from 1974–1976 births.

declined to 242, 155 and 81 mBq Cs-137/l, returning to pre-Chernobyl levels in 1989. Because Cs-137 has a half-life (30 years) similar to Sr-90 (28.7 years), it is logical that environmental (and thus, in vivo) Sr-90 from Chernobyl followed the same general pattern.

Another factor suggesting Chernobyl fallout probably does not account for the fact that post-1989 Sr-90 increases in baby teeth is the consistent finding of higher Sr-90 concentrations near nuclear power plants. Chernobyl fallout levels varied by geographic area, with the northwest US (where there is only one nuclear power reactor, in Washington state) receiving the highest level of radionuclide deposits.

(2) The increase probably does not represent high-level nuclear waste generated by reactors, which is generally stored in deep pools of cooled water or in casks below or above ground. Despite the leakage of some casks, the radioactivity contained in the waste is currently not in the food chain.

(3) Academic-based research reactors also produce fission products. However, these reactors are small in size and few (and declining) in number, which makes it an unlikely reason accounting for such a widespread and sustained trend in Sr-90 in bodies.

(4) Nuclear submarines produce fission products, but they are either contained within the submarine or released into the ocean. Thus, this is not a source of Sr-90 in the food chain, and not a reason for the rise documented in this report.

(5) Emissions from nuclear weapons plants account for another source of Sr-90. However, all reactors involved with producing nuclear weapons ceased manufacturing operations by 1991, and are not likely to play a role in rising Sr-90 concentrations after that time.

(6) While the last above-ground atomic bomb test took place in 1962, subterranean tests at the Nevada Test Site continued. Some of these tests vented radioactivity into the atmosphere. These emissions were much smaller than the atmospheric tests, and the last such test occurred in September 1992 (Norris and Cochran, 1994), making it an unlikely contributor to increases in Sr-90 throughout the 1990s.

(7) Reprocessing of nuclear fuels also creates fission products, but was ceased in the US in the late 1970s, and is not a factor in recent rises in Sr-90.

The only other source of Sr-90 that can explain this steady and dramatic rise in the 1990s is emissions from nuclear power reactors. Because reactors operated a greater percentage of the time, average annual generation of electricity rose 37.5% from 475 000 to 653 000 GW h from 1986–1989 vs. 1994–1997, an increase not markedly different from the 48.5% rise in average Sr-90 levels at birth (US Nuclear Regulatory Commission, 2001). Determining the extent of the correlation between these two trends requires more precise investigation.

Another major finding is that the counties located within 40 miles of each of six nuclear reactors have consistently higher Sr-90 levels than other counties in the same state. These counties were selected to generally correspond with those used by the US National Cancer Institute in a study of cancer near nuclear plants (Jablon et al., 1990). The excess near each nuclear plant ranged, with one exception, from 30.8 to 53.8% higher. More study, assessing whether locally produced radioactivity entering the body from inhalation and/or locally produced food and water account for these consistent differences, is merited. Findings on doses near reactors should be compared with health data. For example, childhood cancer rates near 14 of 14 eastern US reactors exceed the national rate (Mangano et al., 2003).

This analysis of proximity arrives at a different conclusion than an earlier report (O'Donnell et al., 1997) that found no correlation between distance from the Sellafield nuclear plant in western England and Sr-90 levels in baby teeth. That study used a regression equation to test this relationship. There are methodological and analytical differences between the two studies. O'Donnell considered teeth from as far as 300 miles from Sellafield, without taking into account Sr-90 produced by reactors other than Sellafield, while this report used only the counties most proximate (within 40 miles) to reactors. That report tested teeth in batches, while this study used individual readings. Factors other than distance from the radiation source may influence Sr-90 levels in vivo. The uptake of radioactivity in fetal tooth buds depends on intake during pregnancy/early infancy and transfer from maternal bone stores, which vary from person to person. These in turn can be dependent on food and water source, along with dietary differences.

A third major finding is that average Sr-90 concentrations vary geographically. Children from Pennsylvania (mostly near Pottstown, close to Philadelphia) who donated teeth had the highest average Sr-90 of the five states studied. Pottstown lies within 70 miles of 11 operating (and 2 closed) reactors, a concentration unmatched in the US. California, especially areas not close to nuclear reactors, is the state with the lowest average Sr-90. There are only four nuclear reactors on the entire west coast in operation since 1992, compared to dozens in the northeast.

At present (pending more detailed study), nuclear power reactors appear to be the most likely source explaining the recent unexpected rise in Sr-90 concentrations, and elevated Sr-90 levels nearest the plants. The geographic consistency and longevity of these trends and patterns, plus the large number of teeth studied, make these patterns meaningful and (in many instances) statistically significant. The fact that gross beta in US precipitation continued to rise after 1997 and that the highest average Sr-90 level since a low point was reached in 1986 occurred in the most recent birth year studied (1996, 195 mBq Sr-90/g Ca in 30 teeth) suggest that this trend may continue in the near future.

5. Study limitations/opportunities for further study

This report represents the first large-scale study of US in vivo levels of radioactivity in several decades. Although the initial findings presented here are important ones, they raise various questions that should be addressed in future research.

Other unexplored factors may help explain the temporal trends affected here. For example, the current study collected auxiliary data on mother's age at delivery and source of drinking water. Analyzing results by basic characteristics such as gender and race can be performed in future studies. Some factors that affect in vivo levels are already known. For example, children who are breast-fed accumulate lower Sr-90 concentrations than do bottle-fed infants (Rosenthal, 1969). Other dietary differences and their effects on Sr-90 levels can be further explored in future research.

Despite the consistency of results across geographic areas, substantial numbers of teeth were tested from only 5 of 50 US states. More teeth from other states would enhance knowledge about recent patterns of in vivo radioactivity. For example, 19 of the 50 US states (many in the western US) have no operating nuclear reactors, and may display patterns of Sr-90 different than the five already analyzed. The comparison could be extended to nations with no operating nuclear reactors (such as the Philippino teeth mentioned in this report). Testing the hypothesis that these states have lower levels of Sr-90 would be appropriate and necessary in future reporting of results.

The study did not collect sufficient teeth to compare local Sr-90 levels before and after a nuclear reactor opens. The hypothesis that opening a reactor will raise average in vivo concentrations and closing a reactor will reduce them should be tested.

A potential follow-up to this report is to institute a public program measuring in vivo levels in humans and/or animals near nuclear plants for the first time. In addition, more radionuclides in the environment (air, water, soil, etc.) may be tracked. The US government maintains such records near nuclear plants, but has phased out public reporting of several isotopes and failed to perform any long-term analysis.

The data presented herein describe past and current patterns of radioactivity in children's teeth. The three in vivo programs of measuring Sr-90 in US teeth and bones were never accompanied by any reports assessing potential health risks from this radioactivity. The current tooth study previously documented that average Sr-90 levels and childhood cancer rates followed similar trends during atmospheric bomb testing in the 1950s and 1960s. In addition, on Long Island, New York, recent Sr-90 trends correlate closely to trends in childhood cancer incidence, after a 3-year latency period (Gould et al., 2000a). Thus, comparing radioactivity and health patterns should be central to any follow-up of this analysis.

Acknowledgments

Jerry Brown, Ph.D., is acknowledged for his contribution in collecting baby teeth in southeastern Florida.

Appendix A: Determination of Sr-90 to calcium ratio

Sr-90 in deciduous teeth was determined under the direction of Hari D. Sharma, Professor Emeritus of Radiochemistry and president of REMS, Inc., Waterloo, Ontario, Canada. Employing a 1220-003 Quantulus Ultra Low-Level Liquid Scintillation Spectrometer manufactured by the Perkin-Elmer Company in Massachusetts, Dr Sharma followed the following procedure.

Water-washed teeth were treated with 30% hydrogen peroxide for a period of 24 h to ensure that organic material adhering to teeth was oxidized. Teeth were then scrubbed with a hard brush for removing oxidized organic material and the fillings. Teeth were then dried at 110 °C for several minutes and then ground to a fine powder (ball mill). It is very important to remove any filling because if left behind inside a tooth, it tends to give colored solution or dissolution in a mineral acid. The presence of colored solution reduces the efficiency of counting.

Approximately 0.1 g of the powder is weighed in a vial, then digested for a few hours with 0.5 ml of concentrated nitric acid along with solutions containing 5 mg of Sr^{2+} and 2 mg of Y^{3+} carriers at approximately 110 °C on a sand bath. The solution is not evaporated to dryness. The digested powder is transferred to a centrifuge tube by rinsing with tritium-free water. Carbonates of Sr, Y and Ca are precipitated by addition of a saturated solution of sodium carbonate, and then centrifuged. The carbonates are repeatedly washed with a dilute solution of sodium carbonate to remove any coloration from the precipitate. The precipitate is dissolved in hydrochloric acid, and the pH is adjusted to 1.5–2 to make a volume of 2 ml, of which 0.1 ml is set aside for the determination of calcium. The remaining 1.9 ml is mixed with 9.1 ml of scintillation cocktail Ultima Gold AB, supplied by Packard Bioscience BV in a special vial for counting. A blank with appropriate amounts of Ca^{2+}, Sr^{2+} and Y^{3+} is prepared for recording the background.

The activity in the vial with the dissolved tooth is counted four times, 100 min each time, for a total of 400 min, with the scintillation spectrometer, to improve accuracy of results. The background count-rate in the 400–1000 channels is 2.25 ± 0.02 counts/min. The background has been counted for over 5000 min so that the error associated with the background measurement is approximately 1%. The overall uncertainty or one sigma associated with the measurement of Sr-90 per gram of calcium is ± 26 mBq/g Ca.

The efficiency of counting was established using a calibrated solution of Sr-90/Y-90 obtained from the National Institute of Standards and Technology, using the following procedure. The calibrated solution is diluted in water containing a few milligrams of Sr^{2+} solution, and the count-rate from an aliquot of the solution is recorded in channel numbers ranging from 400 to 1000 in order to determine the counting efficiency for the beta particles emitted by Sr-90 and Y-90. It is ensured that the Y-90 is in secular equilibrium with its parent Sr-90 in the solution. The counting efficiency was found to be 1.67 counts per decay of Sr-90 with 1.9 ml of Sr-90/Y-90 solution with 25 mg of Ca^{2+}, 5 mg of Sr^{2+}, 2 mg of Y^{3+} and 9.1 ml of the scintillation cocktail.

The calcium content was determined by using an Inductively Coupled Plasma instrument. The analysis is provided to REMS, Inc., by the University of Waterloo laboratories. REMS is located at P.O. Box 33030, Waterloo, Ontario, Canada, N2T2M9.

Appendix B: Calculation of counting error for Sr-90 in baby teeth due to laboratory observation and sample size

In Tables 3–7, the counting error for average concentrations of Sr-90 is calculated for each state as a combination of two variables: the error due to laboratory observation and the error due to sample size. Calculating each of these errors are as follows, using all 133 teeth (average mBq Sr-90/g Ca=155) from Pennsylvania as an example. These data appear in Table 3.

Lab observation: The count of mBq of Sr-90 is not an exact one, but carries an uncertainty due to limitations of the counter. The error range for an individual tooth is ± 26 mBq, a conservative estimate that may be lower for teeth with larger mass. Thus, the lab observation error for a sample of 133 teeth is

$$26 \text{ mBq}/\sqrt{N} = 26 \text{ mBq}/\sqrt{133} = 2.25 \text{ mBq}$$

Sample size: The error due to the sample size is

$$1/\sqrt{N} = 1/\sqrt{133} = 13.44 \text{ mBq}$$

Calculation: The squares of the two results are added quadratically. Thus,

$$\sqrt{((2.25)^2 + (13.44)^2)} = 13.63 \text{ mBq (rounded to 14)}$$

With an average Sr-90 concentration for the 133 teeth of 155 mBq/g Ca, the confidence interval is between 127 and 183, or 155 plus or minus 28 (2 times 14). Thus, there is a 95% chance that the actual average of the entire population falls within 127 and 183.

Appendix C: Calculation of significance of differences in Sr-90 averages between counties near reactors and more distant counties

In Table 4, average Sr-90 concentrations in teeth from counties near nuclear reactors were compared with averages from other counties in the same state. The significance of differences between the two means was calculated using a *t*-test.

For example, the mean Sr-90 concentration for counties closest to the Indian Point reactor was 164 mBq/g Ca (217 teeth), compared to 121 (317 teeth) for other counties in New York State. The formula used for the significance of this difference is as follows:

Counties near Indian point: $\pm\{1/\sqrt{217}\} \times 164 = 11.1$ (rounded to 11)

Other counties in New York state: $\pm\{1/\sqrt{317}\} \times 121 = 6.8$ (rounded to 7)

$$\{164 - 121\}/\sqrt{(11^2 + 7^2)} = (45/13.04) = 3.45$$

In a basic statistics table, 3.45 standard deviations (z score) indicate a P value of <0.001, i.e. there is less than a 1 in 1000 chance that the difference is due to random chance.

In Tables 5–7, the significance of differences in average Sr-90 concentrations from 1986–1989 to 1994–1997 were tested using a similar technique. For example, using Florida data in Table 6

1986−1989; for 102 teeth, average mBq Sr-90/g Ca=112

1994−1997; for 99 teeth, average mBq Sr-90/g Ca=153

$1986-1989 = \pm\{1/\sqrt{102}\} \times 112 = 11.1$ (rounded to 11)

$1994-1997 = \pm\{1/\sqrt{99}\} \times 153 = 15.4$ (rounded to 15)

$$\{153 - 112\}/\sqrt{(11^2 + 15^2)} = 2.20$$

In a basic statistics table, 2.20 standard deviations (z score) indicate a P value of <0.04, i.e. there is less than a 4 in 100 chance that the difference is due to random chance.

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Infant Death and Childhood Cancer Reductions after Nuclear Plant Closings in the United States

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Abstract

Subsequent to 1987, 8 U.S. nuclear plants located at least 113 km from other reactors ceased operations. Strontium-90 levels in local milk declined sharply after closings, as did deaths among infants who had lived downwind and within 64 km of each plant. These reductions occurred during the first 2 yr that followed closing of the plants, were sustained for at least 6 yr, and were especially pronounced for birth defects. Trends in infant deaths in proximate areas not downwind, and more than 64 km from the closed plants, were not different from the national patterns. In proximate areas for which data were available, cancer incidence in children younger than 5 yr of age fell significantly after the shutdowns. Changes in health following nuclear reactor closings may help elucidate the relationship between low-dose radiation exposure and disease.

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Key Words

- childhood cancer,
- downwind,
- infant death,
- nuclear plant closings,
- nuclear reactors,
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Ernest J. Sternglass, Ph. D.

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Competitors To Nuclear: Eat My Dust

Private investors have flatly rejected nuclear power but enthusiastically bought its main supply-side competitors—decentralized cogeneration and renewables.

In a market economy, private investors are the ultimate arbiter of what energy technologies can compete and yield reliable profits, so to understand nuclear power's prospects, just follow the money. Private investors have flatly rejected nuclear power but enthusiastically bought its main supply-side competitors—decentralized cogeneration and renewables. Worldwide, by the end of 2004, these supposedly inadequate alternatives (see graph, p. 1) had more installed capacity than nuclear, produced 92% as much electricity, and were growing 5.9 times faster and accelerating, while nuclear was fading.

The world's nuclear plant vendors have never made money, and their few billion dollars' dwindling annual revenue hardly qualifies them any more as a serious global business. In contrast, the renewable power industry earns ~$23 billion a year by adding ~12 GW of capacity every year: in 2004, 8 GW of wind, 3 GW of geothermal/small hydro/biomass/wastes, and 1 GW of photovoltaics (69% of nuclear's 2004 new construction starts, which PVs should surpass this year). PV and windpower markets, respectively doubling about every two and three years, are expected to make renewable power a $35-billion business within eight years. And distributed fossil-fueled cogeneration of heat and power added a further 15 GW in 2004; it does release carbon, but ~30% less than the separate boilers and power plants it replaces, or up to ~80% less with fuel-switching.

Windpower's 50+ gigawatts of global capacity, half of U.S. nuclear power capacity, paused in 2004 due to Congressional wrangling, but is expected to triple in the next four years, mainly in Europe, which aims to get 22% of its electricity from renewables by 2010. One-fifth of Denmark's power now comes from wind; German and Spanish windpower are each adding as much capacity *each year* (2 GW) as the global nuclear industry is annually adding on average during 2000–10. No country has had or expects economic or technical obstacles to further major wind expansion. The International Energy Agency forecast in 2003 that in 2010, wind could add nine times as much capacity as nuclear added in 2004, or 84 times its planned 2010 addition. Eight years hence, just wind plus industry-forecast PVs could surpass installed global nuclear capacity. The market increasingly resembles a 1995 Shell scenario with half of global energy, and virtually all growth, coming from renewables by mid-century—about what it would take, with conservative efficiency gains, to stabilize atmospheric carbon.

Whenever nuclear power's competitors (even just on the supply side) were allowed to compete fairly, they've far outpaced central stations. Just in 1982–85, California utilities acquired and or were firmly offered enough cost-effective savings and decentralized supplies to meet all demand with no central fossil-fueled or nuclear plants. (Alas, before the cheaper alternatives could displace all those plants—and thus avert the 2000 power crisis—state regulators, spooked by success, halted the bidding.)

Today's nonnuclear technologies are far better and cheaper. They're batting 1.000 in the more competitive and transparent processes that have swept most market economies' electricity sectors and are emerging even in China and Russia. A few Stalinist economies like North Korea, Zimbabwe, and Belarus still offer ideal conditions for nuclear sales, but they won't order much, and you wouldn't want to live there.

No wonder the world's universities have dissolved or reorganized nearly all of their departments of nuclear engineering, and none still attracts top students—another portent that the business will continue to fall, as Nobel physicist Hannes Alfvén warned, "into ever less competent hands," buying ever less solution to any unresolved problem than in the days of the pioneers. Their intentions were worthy, their efforts immense, but their hopes of abundant and affordable nuclear energy failed in the marketplace.

—Amory B. Lovins

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New-Build Nuclear Is Dead: Morningstar

Nuclear reactors are not a viable source of new power in the West, Morningstar analysts conclude in a report this month to institutional investors.

Anti-nuclear protesters demonstrate in Spain. Morningstar cites political opposition as one of the reasons that "new-build nuclear in the West is dead." (Photo credit: Wikipedia)

Nuclear's "enormous costs, political and popular opposition, and regulatory uncertainty" render new reactors infeasible even in regions where they make economic sense, according to Morningstar's Utilities Observer report for November.

"Aside from the two new nuclear projects in the U.S., one in France, and a possible one in the U.K., we think new-build nuclear in the West is dead," Morningstar analysts Mark Barnett and Travis Miller say in the report.

This view puts Morningstar on the same page as former Exelon CEO John Rowe, who said in early 2012 that new nuclear plants "don't make any sense right now" and won't become economically viable for the forseeable future.

Some nuclear cheerleaders continue to champion reactors as a source of new power, like members of an industry panel I covered last year who declared a renaissance of the nuclear renaissance and predicted nuclear plants would replace aging fossil fuel plants. They include the executive director of Exelon Nuclear Partners, who said, "The future of nuclear is looking pretty good."

The Morningstar analysts call the nuclear renaissnace a "fiction" and a "fantasy," at least in the West.

"The economies of scale experienced in France during its initial build-out and the related strength of supply chain and labor pool were imagined by the dreamers who have coined the term 'nuclear renaissance' for the rest of the world. But outside of China and possibly South Korea this concept seems a fantasy, as should become clearer examining even theoretical projections for new nuclear build today."

South Korea is in the midst of an economy-wide build out of third-generation nuclear reactors. China has 17 reactors now, 30 under construction, and many more planned.

While nuclear development in Asia is good news for nuclear equipment suppliers, the analysts say, it could ultimately lead to bad news.

"China in particular is building reactors at a pace that should raise concerns about safety and construction quality regardless of the sophistication of developers."

The Morningstar analysts considered conditions about a decade ahead, Miller told me, or until the energy markets change significantly from today's environment.

"That obviously could mean decades if we continue to be in an environment with low gas prices, slow-growth power demand and environmental opposition," Miller said via email.

They considered traditional forms of nuclear generation—pressurized water reactors, boiling water reactors—and did not consider the small modular reactors championed by the Obama Administration, the depleted-uranium reactors championed by Bill Gates, or other next-generation designs.

In the Morningstar report, only Exelon earns the analysts' wide-moat rating for its economic position.

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$1 Billion Nuclear Power Project Abandoned In Iowa

Jake Richardson

Plans for Iowa's second nuclear power plant have been dropped by Mid American Energy. No design has been approved for the type of nuclear plant the company had intended, so they have let the idea go. It was reported that ratepayers will be refunded the $8.8 million they paid for a completed feasibility study. Sites not far from Council Bluffs and Davenport were being considered for the plant.

The

(Iowa's one nuclear power plant.) Image Credit: Jssteinke

decreasing cost of natural gas, events at Fukushima and a general suspicion about the safety of nuclear power may have all contributed to the decision to abandon the development of a new nuclear plant. Another factor may have been Iowa's leading success with wind power development and its continuing investment in that form of clean, renewable energy. Mid-American will focus on its new wind power projects there.

Reactions to the announcement didn't appear to be that low over the loss of extra nuclear power in the area. Environmentalists were predictably jazzed, "Yay! We are glad to hear that they are planning to expand their wind power. We think that is a better option than nuclear power," said Neila Seaman, director of the Iowa Chapter of Sierra Club. (Source: Des Moines Register)

Friends of the Earth interpreted the decision more broadly saying it is an indication that massive public subsidies for new nuclear power might not be as popular an idea any longer. A poll of Iowans conducted in 2012 found 77% were against a funding arrangement that would have required residents to have to pay the energy company up front for construction of the nuclear plant. Proposed legislation could have made such an arrangement possible, but it was opposed by a number of non-profit advocacy organizations, so it didn't go through.

Iowa's only nuclear plant is located near Cedar Rapids and generates about 615 MW. It began operation in 1974, and uses one General Electric boiling water reactor.

Tags: iowa

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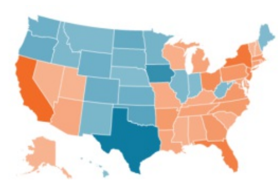

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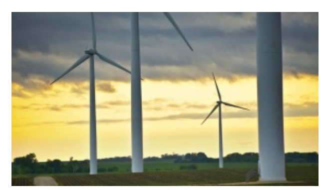

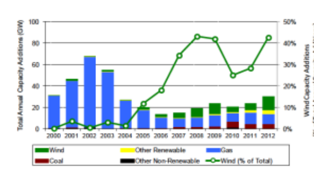

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Buffett's MidAmerican Energy Holding Forms Renewables Unit

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"This is a vote for renewable energy, not a bet," says MidAmerican VP.

Herman K. Trabish
January 26, 2012

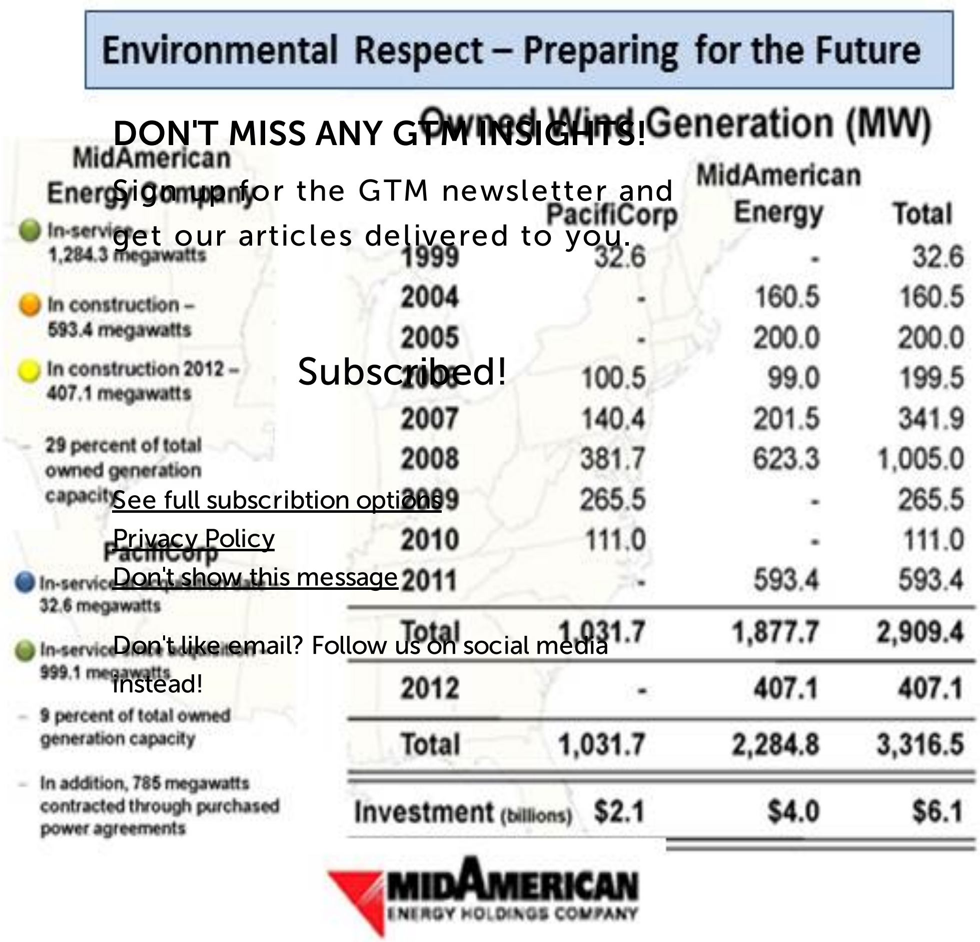
MidAmerican Energy Holding Company, the Midwestern utility subsidiary of Warren Buffett's Berkshire Hathaway, announced today it will form a branch dedicated exclusively to the development of renewable energy.

The renewables platform will, unlike four of MidAmerican's five other highly regulated platforms (two utilities and two gas pipelines), offer MidAmerican the opportunity it has only had in its CalEnergy geothermal and cogeneration platform -- namely, to invest outside the strictures of regulatory obligations and with regard solely for its shareholders.

MidAmerican Renewables LLC will have four subunits. MidAmerican Solar will encompass such recent MidAmerican investments as the 550-megawatt AC Topaz solar power plant in California and the 290-megawatt AC Agua Caliente project in Arizona. MidAmerican Wind will incorporate the 3,360-plus megawatts of wind the company owns, including new investments like the nearly 600 megawatts of Midwestern wind the utility has purchased since 2010.

MidAmerican Geothermal will incorporate the company's existing holdings under its CalEnergy brand. The new venture will also include MidAmerican Hydro.

The most exciting part of this, explained MidAmerican Vice President for federal policy Jonathan Weisgall, is the unregulated nature of the undertaking. A utility has to meet the dictates of federal, state and local regulators and a gas pipeline builder is governed by the Federal Energy Regulatory Commission (FERC). MidAmerican Renewables will be free to invest shareholders' money as it sees fit.



	PacifiCorp	MidAmerican Energy	Total
1999	32.6	-	32.6
2004	-	160.5	160.5
2005	-	200.0	200.0
2006	100.5	99.0	199.5
2007	140.4	201.5	341.9
2008	381.7	623.3	1,005.0
2009	265.5	-	265.5
2010	111.0	-	111.0
2011	-	593.4	593.4
Total	1,031.7	1,877.7	2,909.4
2012	-	407.1	407.1
Total	1,031.7	2,284.8	3,316.5
Investment (billions)	$2.1	$4.0	$6.1

Despite hostile publicity about renewables arising from loan guarantees and other federal support efforts, the Buffett people believe investing in the sector is a financially smart move.

“We look forward to expanding our wind, geothermal, solar and hydro portfolio,” said MidAmerican Energy chairman, president and CEO Greg Abel. “We believe the need for renewable energy will continue to grow.”

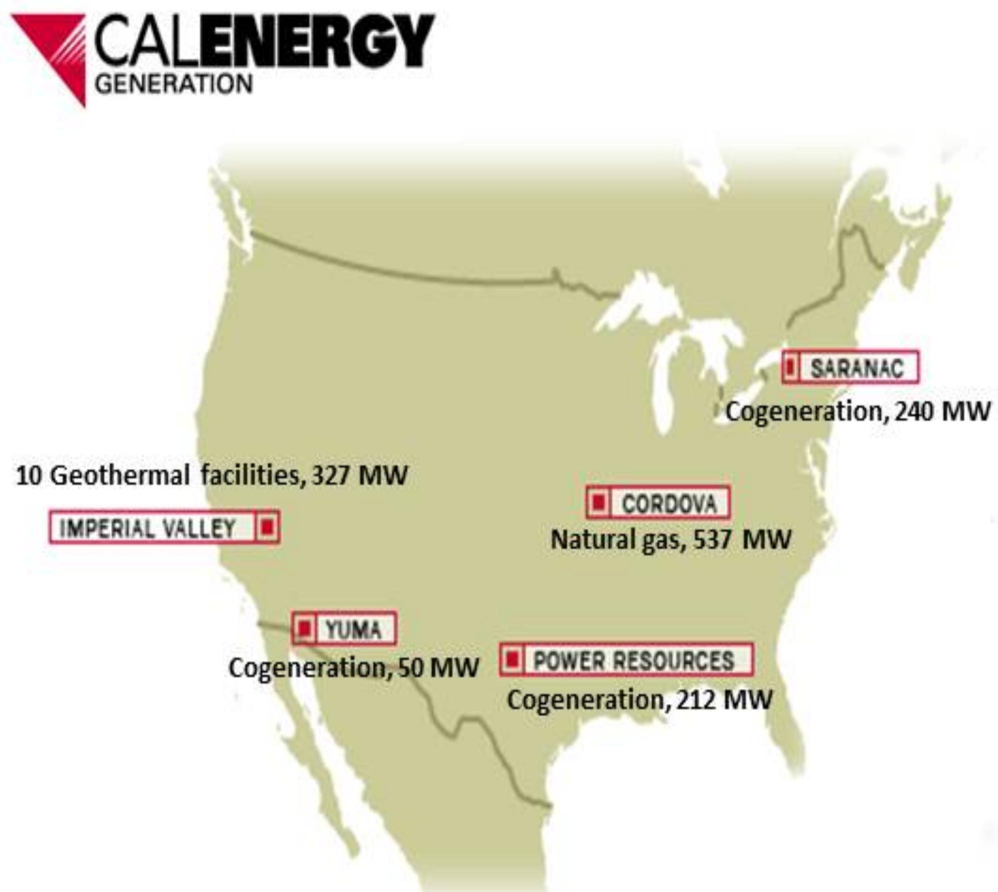
Like other well-capitalized, high-profile investors such as Google and Ted Turner, the Buffett company believes this increased emphasis on renewables in its portfolio is a solid business decision that will pay off over time.

“This is a vote for renewable energy,” Weisgall told GTM in discussing why Warren Buffett, perhaps the nation’s premier investment maven, is for this move. “It is not a bet.”

Weisgall said there is no specific budget or capitalization for the renewables entity but pointed to MidAmerican Energy’s steadily increasing renewables buys in recent years as an indication of the new branch’s financial scope. In addition to $6.1 billion invested in wind, largely since 2008, the company reportedly put some $3 billion into the two late-2011 solar power plant investments.

Federal policy and tax credits that help keep renewables on a level playing field with more mature electricity sources figure into MidAmerican’s strategy, according to Weisgall. While in an unregulated market one hundred percent of the benefits from investments that earn tax credits and tax benefits such as accelerated depreciation go directly to MidAmerican’s customers, the new unit created to operate in unregulated markets will give MidAmerican the opportunity to assume the role of developer and take advantage of the incentives. But MidAmerican is not gambling on these incentives being in place.

While wind’s vital production tax credit (PTC) expires on the last day of 2012, the solar investment tax credit (ITC) will remain in place through 2016 and geothermal’s tax credit extends to the end of 2013. The benefits these tax credits offer to MidAmerican are part of the company's attraction to solar and geothermal.



As for wind, all of MidAmerican's most recent wind buys, including the 81-megawatt Bishop Hill II project in Illinois, will be in the ground by the end of 2012, Weisgall pointed out, making them eligible for the current PTC. He and others in the renewables industries still hold out hope that a PTC extension and a restoration of the accelerated depreciation to 100 percent from its recent cut to 50 percent will be included in the tax extenders package due to come before Congress at the end of February.

"But we cannot count on a tax credit, and we will work with the facts as they are," Weisgall said. Wind may remain a viable investment for MidAmerican stakeholders because of its increasingly competitive levelized cost of electricity. Or, Weisgall admitted, wind may not continue to be part of the new renewables unit's portfolio.

In keeping with the Berkshire Hathaway commitment to frugality on behalf of its stockholders, officers at MidAmerican Energy will assume supervision of the new renewables units, Weisgall said. Only one new hire will be brought on.

TAGS: accelerated depreciation, agua caliente project, arizona, berkshire hathaway, bishop hill ii, calenergy, california, capitalization, cogeneration, congress, customers, electricity sources, federal energy regulatory commission, federal policy, federal regulators

Executive Summary

Conspicuously absent from industry press releases and briefing memos touting nuclear power's potential as a solution to global warming is any mention of the industry's long and expensive history of taxpayer subsidies and excessive charges to utility ratepayers. These subsidies not only enabled the nation's existing reactors to be built in the first place, but have also supported their operation for decades.

The industry and its allies are now pressuring all levels of government for large new subsidies to support the construction and operation of a new generation of reactors and fuel-cycle facilities. The substantial political support the industry has attracted thus far rests largely on an uncritical acceptance of the industry's economic claims and an incomplete understanding of the subsidies that made—and continue to make—the existing nuclear fleet possible.

Such blind acceptance is an unwarranted, expensive leap of faith that could set back more cost-effective efforts to combat climate change. A fair comparison of the available options for reducing heat-trapping carbon emissions while generating electricity requires consideration not only of the private costs of building plants and their associated infrastructure but also of the public subsidies given to the industry. Moreover, nuclear power brings with it important economic, waste disposal, safety, and security risks unique among low-carbon energy sources. Shifting these risks and their associated costs onto the public is the major goal of the new subsidies sought by the industry (just as it was in the past), and by not incorporating these costs into its estimates, the industry presents a skewed economic picture of nuclear power's value compared with other low-carbon power sources.

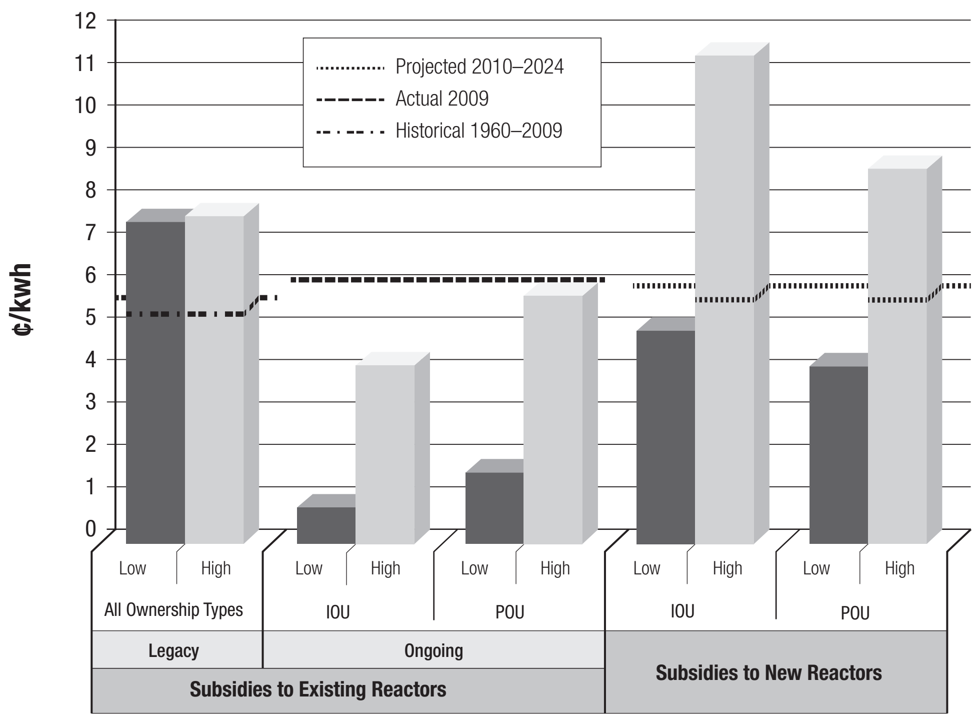
SUBSIDIES OFTEN EXCEED THE VALUE OF THE ENERGY PRODUCED

This report catalogues in one place and for the first time the full range of subsidies that benefit the nuclear power sector. The findings are striking: since its inception more than 50 years ago, the nuclear power industry has benefited—and continues to benefit—from a vast array of preferential government subsidies. Indeed, as Figure ES-1 (p. 2) shows, subsidies to the nuclear fuel cycle have often exceeded the value of the power produced. This means that buying power on the open market and giving it away for free would have been less costly than subsidizing the construction and operation of nuclear power plants. Subsidies to new reactors are on a similar path.

Throughout its history, the industry has argued that subsidies were only temporary, a short-term stimulus so the industry could work through early technical hurdles that prevented economical reactor operation. A 1954 advertisement from General Electric stated that, "In five years—certainly within ten," civilian reactors would be "privately financed, built without government subsidy." That day never arrived and, despite industry claims to the contrary, remains as elusive as ever.

The most important subsidies to the industry do not involve cash payments. Rather, they shift construction-cost and operating risks from investors to taxpayers and ratepayers, burdening taxpayers with an array of risks ranging from cost overruns and defaults to accidents and nuclear waste management. This approach, which has remained remarkably consistent throughout the industry's history, distorts market choices that would otherwise favor less risky investments. Although it may not involve direct cash payments, such favored

Figure ES-1. Nuclear Subsidies Compared to EIA Power Prices



Note: Legacy subsidies are compared to the Energy Information Administration (EIA) average 1960–2009 industrial power price (5.4 ¢/kWh). Ongoing subsidies are compared to EIA 2009 actual power prices for comparable busbar plant generation costs (5.9 ¢/kWh). Subsidies to new reactors are compared to EIA 2009 reference-case power prices for comparable busbar plant generation costs (5.7 ¢/kWh).

treatment is nevertheless a subsidy, with a profound effect on the bottom line for the industry and taxpayers alike.

Reactor owners, therefore, have never been economically responsible for the full costs and risks of their operations. Instead, the public faces the prospect of severe losses in the event of any number of potential adverse scenarios, while private investors reap the rewards if nuclear plants are economically successful. For all practical purposes, nuclear power's economic gains are privatized, while its risks are socialized.

Recent experiences in the housing and financial markets amply demonstrate the folly of arrangements that separate investor risk from reward. Indeed, massive new subsidies to nuclear power could encourage utilities to make similarly speculative, expensive investments in nuclear plants—investments that would never be tolerated if the actual risks were properly accounted for and allocated.

While the purpose of this report is to quantify the extent of past and existing subsidies, we are not blind to the context: the industry is calling for even more support from Congress. Though the value of these new subsidies is not quantified in this report, it is clear that they would only further increase the taxpayers' tab for nuclear power while shifting even more of the risks onto the public.

LOW-COST CLAIMS FOR EXISTING REACTORS IGNORE HISTORICAL SUBSIDIES

The nuclear industry is only able to portray itself as a low-cost power supplier today because of past government subsidies and write-offs. First, the industry received massive subsidies at its inception, reducing both the capital costs it needed to recover from ratepayers (the "legacy" subsidies that underwrote reactor construction through the 1980s) and its operating costs (through ongoing subsidies to inputs, waste management, and accident risks). Second, the industry wrote down tens of billions of dollars in capital costs after its first generation of reactors experienced large cost overruns, cancellations, and plant abandonments, further reducing the industry's capital-recovery requirements. Finally, when industry restructuring revealed that nuclear power costs were still too high to be competitive, so-called stranded costs were shifted to utility ratepayers, allowing the reactors to continue operating.

These legacy subsidies are estimated to exceed seven cents per kilowatt-hour (¢/kWh)—an amount equal to about 140 percent of the average wholesale price of power from 1960 to 2008, making the subsidies more valuable than the power produced by nuclear plants over that period. Without these subsidies, the industry would have faced a very different market reality—one in which many reactors would never have been built, and utilities that did build reactors would have been forced to charge consumers even higher rates.

ONGOING SUBSIDIES CONTRIBUTE TO NUCLEAR POWER'S PERCEIVED COST ADVANTAGE

In addition to legacy subsidies, the industry continues to benefit from subsidies that offset the costs of uranium, insurance and liability, plant security, cooling water, waste disposal, and plant decommissioning. The value of these subsidies is harder to pin down with specificity, with estimates ranging from a low of 13 percent of the value of the power produced to a high of 98 percent. The breadth of this range largely reflects three main factors: uncertainty over the dollar value of accident liability caps; the value to publicly owned utilities (POUs) of ongoing subsidies such as tax breaks and low return-on-investment requirements; and generous capital subsidies to investor-owned utilities (IOUs) that have declined as the aging, installed capacity base is fully written off.

Our low-end estimate for subsidies to existing reactors (in this case, investor-owned facilities) is 0.7 ¢/kWh, a figure that may seem relatively small at only 13 percent of the value of the power produced. However, it represents more than 35 percent of the nuclear production costs (operation and maintenance costs plus fuel costs, without capital recovery) often cited by the industry's main trade association as a core indicator of nuclear power's competitiveness; it also represents nearly 80 percent of the production-cost advantage of nuclear relative to coal. With ongoing subsidies to POUs nearly double those to IOUs, the impact on competitive viability is proportionally higher for publicly owned plants.

SUBSIDIES TO NEW REACTORS REPEAT PAST PATTERNS

Legacy and ongoing subsidies to existing reactors may be important factors in keeping facilities operating, but they are not sufficient to attract new investment in nuclear infrastructure. Thus an array of new subsidies was rolled out during the past decade, targeting not only reactors but also other fuel-cycle facilities. Despite the profoundly poor investment experience with taxpayer subsidies to nuclear plants over the past 50 years, the objectives of these new subsidies are precisely the same as the earlier subsidies: to reduce the private cost of capital for new nuclear reactors and to shift the long-term, often multi-generational risks of the nuclear fuel cycle away from investors. And once again, these subsidies to new reactors—whether publicly or privately owned—could end up exceeding the value of the power produced (4.2 to 11.4 ¢/kWh, or 70 to 200 percent of the projected value of the power).

It should be noted that certain subsidies to new reactors are currently capped at a specific dollar amount, limited to a specific number of

Methodology: How We Estimated Nuclear Subsidies

Identifying and valuing subsidies to the nuclear fuel cycle for this report involved a broad review of dozens of historical studies and program assessments, industry statements and presentations, and government documents. The result is an in-depth and comprehensive evaluation that groups nuclear subsidies by type of plant ownership (public or private), time frame of support (whether the subsidy is ongoing or has expired), and the specific attribute of nuclear power production the subsidy is intended to support.

Plant ownership

Subsidies available to investor-owned and publicly owned utilities are not identical, so were tracked separately.

Time frame of support

The data were organized into:

- **Legacy subsidies**, which were critical in helping nuclear power gain a solid foothold in the U.S. energy sector but no longer significantly affect pricing
- **Ongoing subsidies to existing reactors**, which continue to affect the cost of electricity produced by the 104 U.S. nuclear reactors operating today
- **Subsidies to new reactors**, which are generally provided in addition to the ongoing subsidies available to existing reactors

A further set of subsidies proposed for the nuclear sector but not presently in U.S. statutes is discussed qualitatively but not quantified.

Attribute of production

The following subcategories were modeled on the structure commonly used internationally (as by the Organisation for Economic Cooperation and Development):

- **Factors of production**—subsidies intended to offset the cost of capital, labor, and land
- **Intermediate inputs**—subsidies that alter the economics of key inputs such as uranium, enrichment services, and cooling water
- **Output-linked support**—subsidies commensurate with the quantity of power produced
- **Security and risk management**—subsidies that address the unique and substantial safety risks inherent in nuclear power
- **Decommissioning and waste management**—subsidies that offset the environmental or plant-closure costs unique to nuclear power

To enable appropriate comparisons with other energy options, the results are presented in terms of levelized cents per kilowatt-hour and as a share of the wholesale value of the power produced. Inclusion of industry and historical data sources for some component estimates means that some of the levelization inputs were not transparent. Where appropriate, a range of estimates was used to reflect variation in the available data or plausible assumptions.

reactors, or available only in specific states or localities. Therefore, although all the subsidies may not be available to each new reactor, the values shown in Figure ES-1 are reasonably representative of the subsidies that will be available to the first new plants to be built. Furthermore, it is far from clear whether existing caps will be binding. Recent legislative initiatives would expand eligibility for these subsidies to even more reactors and extend the period of eligibility during which these subsidies would be available.

KEY SUBSIDY FINDINGS

Government subsidies have been directed to every part of the nuclear fuel cycle. The most significant forms of support have had four main goals: reducing the cost of capital, labor, and land (i.e., factors of production), masking the true costs of producing nuclear energy ("intermediate inputs"), shifting security and accident risks to the public, and shifting long-term operating risks (decommissioning and waste management) to the public. A new category of subsidy, "output-linked support," is directed at reducing the price of power produced. Table ES-1 shows the estimated value of these subsidies to existing and new reactors. The subsequent sections discuss each type of subsidy in more detail.

A. Reducing the Cost of Capital, Labor, and Land (Factors of Production)

Nuclear power is a capital-intensive industry with long and often uncertain build times that exacerbate both the cost of financing during construction and the market risks of misjudging demand. Historically, investment tax credits, accelerated depreciation, and other capital subsidies have been the dominant type of government support for the industry, while subsidies associated with labor and land costs have provided lesser (though still relevant) support.

Legacy subsidies that reduced the costs of these inputs were high, estimated at 7.2 ¢/kWh. Ongoing subsidies to existing reactors are much lower but still significant, ranging from 0.06 to 1.94 ¢/kWh depending on ownership structure. For new reactors, accelerated depreciation has been supplemented with a variety of other capital subsidies to bring plant costs down by shifting a large portion of the capital risk from investors to taxpayers. The total value of subsidies available to new reactors in this category is significant for both POUs and IOUs, ranging from 3.51 to 6.58 ¢/kWh. These include:

- **Federal loan guarantees.** Authorized under Title 17 of the Energy Policy Act (EPACT) of 2005, federal loan guarantees are the largest construction subsidy for new, investor-owned reactors, effectively shifting the costs and risks of financing and building a nuclear plant from investors to taxpayers. The industry's own estimates,

Table ES-1. Subsidies to Existing and New Reactors

	Subsidies to Existing Reactors (¢/kWh)			Subsidies to New Reactors (¢/kWh)	
	Legacy	Ongoing			
Subsidy Type	All Ownership Types	IOU	POU	IOU	POU
Factors of production	7.20	0.06	0.96–1.94	3.51–6.58	3.73–5.22
Intermediate inputs	0.10–0.24	0.29–0.51	0.16–0.18	0.21–0.42	0.21–0.42
Output-linked support	0.00	0.00	0.00	1.05–1.45	0.00
Security and risk management	0.21–0.22	0.10–2.50	0.10–2.50	0.10–2.50	0.10–2.50
Decommissioning and waste management	No data available	0.29–1.09	0.31–1.15	0.13–0.48	0.16–0.54
Total	**7.50–7.66**	**0.74–4.16**	**1.53–5.77**	**5.01–11.42**	**4.20–8.68**
Share of power price	139%–142%	13%–70%	26%–98%	84%–190% (high)	70%–145% (high)
				88%–200% (reference)	74%–152% (reference)

Note: A range of subsidy values is used where there was a variance in available subsidy estimates. To determine the subsidy's share of the market value of the power produced, legacy subsidies are compared to the Energy Information Administration (EIA) average 1960–2009 industrial power price (5.4 ¢/kWh). Ongoing subsidies are compared to EIA 2009 power prices for comparable busbar plant generation costs (5.9 ¢/kWh). Subsidies to new reactors are compared to EIA 2009 high- and reference-case power prices for comparable busbar plant generation costs (6.0 and 5.7 ¢/kWh, respectively); using the low case would have resulted in even higher numbers.

which we have used despite large subsequent increases in expected plant costs, place the value of this program between 2.5 and 3.7 ¢/kWh. Total loan guarantees are currently limited to $22.5 billion for new plants and enrichment facilities, but the industry has been lobbying for much higher levels.

Loan guarantees not only allow firms to obtain lower-cost debt, but enable them to use much more of it—up to 80 percent of the project's cost. For a single 1,600-megawatt (MW) reactor, the loan guarantee alone would generate subsidies of $495 million per year, or roughly $15 billion over the 30-year life of the guarantee.

- **Accelerated depreciation.** Allowing utilities to depreciate new reactors over 15 years instead of their typical asset life (between 40 and 60 years) will provide the typical plant with a tax break of approximately $40 million to $80 million per year at current construction cost estimates. Rising plant costs, longer service lives, and lower capacity factors would all increase the value of current accelerated depreciation rules to IOUs. This subsidy is not available to POUs because they pay no taxes.
- **Subsidized borrowing costs to POUs.** The most significant subsidy available to new publicly owned reactors is the reduced cost of borrowing made possible by municipal bonds and new Build America Bonds, which could be worth more than 3 ¢/kWh.
- **Construction work in progress.** Many states allow utilities to charge ratepayers for construction work in progress (CWIP) by adding a surcharge to customers' bills. This shifts financing and construction risks (including the risk of cost escalations and/or plants being abandoned during construction) from investors to customers. CWIP benefits both POUs and IOUs and is estimated to be worth between 0.41 and 0.97 ¢/kWh for new reactors.
- **Property-tax abatements.** Support for new plants is also available through state and local governments, which provide a variety of plant-specific subsidies that vary by project.

B. Masking the True Costs of Producing Nuclear Energy (Intermediate Inputs)

A variety of subsidies masks the costs of the inputs used to produce nuclear power. Uranium fuel costs, for example, are not a major element in nuclear economics, but subsidies to mining and enrichment operations contribute to the perception of nuclear power as a low-cost energy source. In addition, the under-pricing of water used in bulk by nuclear reactors has significant cost implications. The value of such legacy subsidies to existing reactors is estimated between 0.10 and 0.24 ¢/kWh, and the value of ongoing subsidies is estimated between 0.16 and 0.51 ¢/kWh. The value of such subsidies to new reactors is estimated between 0.21 and 0.42 ¢/kWh. Subsidized inputs include:

- **Fuel.** The industry continues to receive a special depletion allowance for uranium mining equal to 22 percent of the ore's market value, and its deductions are allowed to exceed the gross investment in a given mine. In addition, uranium mining on public lands is governed by the antiquated Mining Law of 1872, which allows valuable ore to be taken with no royalties paid to taxpayers. Although no relevant data have been collected on the approximately 4,000 mines from which uranium has been extracted in the past, environmental remediation costs at some U.S. uranium milling sites actually exceeded the market value of the ore extracted.
- **Uranium enrichment.** Uranium enrichment, which turns mined ore into reactor fuel, has benefited from substantial legacy subsidies. New plants that add enrichment capacity will receive subsidies as well, in the form of federal loan guarantees. Congress has already authorized $2 billion in loan guarantees for a new U.S. enrichment facility, and the Department of

Energy has allocated an additional $2 billion for this purpose. While we could not estimate the per-kilowatt-hour cost of this subsidy because it depends on how much enrichment capacity is built, the $4 billion represents a significant new subsidy to this stage of the fuel cycle.

- **Cooling water.** Under-priced cooling water is an often-ignored subsidy to nuclear power, which is the most water-intensive large-scale thermal energy technology in use. Even when the water is returned to its source, the large withdrawals alter stream flow and thermal patterns, causing environmental damage. Available data suggest that reactor owners pay little or nothing for the water consumed, and are often given priority access to water resources—including exemption from drought restrictions that affect other users. While we provide a low estimate of water subsidies (between $600 million and $700 million per year for existing reactors), more work is needed to accurately quantify this subsidy—particularly as water resources become more constrained in a warming climate.

C. Reducing the Price of Power Produced (Output-Linked Support)

Until recently, subsidies linked to plant output were not a factor for nuclear power. That changed with the passage of EPACT in 2005, which granted new reactors an important subsidy in the form of:

- **Production tax credits (PTCs).** A PTC will be granted for each kilowatt-hour generated during a new reactor's first eight years of operation; at present, this credit is available only to the first plants to be built, up to a combined total capacity of six gigawatts. While EPACT provides a nominal PTC of 1.8 ¢/kWh, payments are time-limited. Over the full life of the plant, the PTC is worth between 1.05 and 1.45 ¢/kWh. Under current law, PTCs are not available to POUs (since POUs do not pay taxes), but there have been legislative efforts to enable POUs to capture the value of the tax credits by selling or transferring them to other project investors that do pay taxes.

D. Shifting Security and Accident Risks to the Public (Security and Risk Management)

Subsidies that shift long-term risks to the public have been in place for many years. The Price-Anderson Act, which caps the nuclear industry's liability for third-party damage to people and property, has been a central subsidy to the industry for more than half a century.

Plant security concerns have increased significantly since 9/11, and proliferation risks will increase in proportion to any expansion of the civilian nuclear sector (both in the United States and abroad). The complexity and lack of data in these areas made it impossible to quantify the magnitude of security subsidies for this analysis. But it is clear that as the magnitude of the threat increases, taxpayers will be forced to bear a greater share of the risk. Subsidies that shift these risks are associated with:

- **The Price-Anderson Act.** This law requires utilities to carry a pre-set amount of insurance for off-site damages caused by a nuclear plant accident, and to contribute to an additional pool of funds meant to cover a pre-set portion of the damages. However, the law limits total industry liability to a level much lower than would be needed in a variety of plausible accident scenarios. This constitutes a subsidy when compared with other energy sources that are required to carry full private liability insurance, and benefits both existing and new reactors.

  Only a few analysts have attempted to determine the value of this subsidy over its existence, with widely divergent results: between 0.1 and 2.5 ¢/kWh. More work is therefore needed to determine how the liability cap affects plant economics, risk-control decisions, and risks to the adjacent population.

- **Plant security.** Reactor operators must provide security against terrorist attacks or other threats of a certain magnitude, referred to as the "design basis threat." For threats of a greater magnitude (a larger number of attackers, for example), the government assumes all financial responsibility, which constitutes another type of subsidy. It is difficult to quantify the value of this taxpayer-provided benefit because competing forms of energy do not carry similar risks. But it is important that plant security costs be reflected in the cost of power delivered to consumers, rather than supported by taxpayers in general.

- **Proliferation.** The link between an expanded civilian nuclear sector and proliferation of nuclear weapons or weapons technology is fairly widely accepted. It is also consistently ignored when assessing plant costs—much as investors in coal plants ignored the cost of carbon controls until recently. Though quantifying proliferation costs may be difficult, assuming they are zero is clearly wrong. These ancillary impacts should be fully assessed and integrated into the cost of nuclear power going forward.

E. Shifting Long-Term Operating Risks to the Public (Decommissioning and Waste Management)

The nuclear fuel cycle is unique in the types of long-term liabilities it creates. Reactors and fuel-cycle facilities have significant end-of-life liabilities associated with the proper closure, decommissioning, and decontamination of facilities, as well as the safe management of nuclear waste over thousands of years. The industry has little operational experience with such large and complex undertakings, greatly increasing the likelihood of dramatic cost overruns. In total, the subsidies that shift these long-term operating risks to the public amount to between 0.29 and 1.09 ¢/kWh for existing reactors and between 0.13 and 0.54 ¢/kWh for new reactors. The specific subsidies that do the shifting are associated with:

- **Nuclear waste management.** The federal Nuclear Waste Repository for spent fuel is expected to cost nearly $100 billion over its projected operating life, 80 percent of which is attributed to the power sector. A congressionally mandated fee on nuclear power consumers,

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The Industry's Shopping List: New Subsidies Under Consideration

The following nuclear subsidies, as proposed in the American Power Act (APA) and the American Clean Energy Leadership Act (ACELA), would not necessarily be available to every new reactor, but their collective value to the industry would be significant:

- A clean-energy bank that could promote nuclear power through much larger loans, letters of credit, loan guarantees, and other credit instruments than is currently possible
- Tripling federal loan guarantees available to nuclear reactors through the Department of Energy, from $18.5 billion to $54 billion
- Reducing the depreciation period for new reactors from 15 years to five
- A 10 percent investment tax credit for private investors or federal grants in lieu of tax payments to publicly owned and cooperative utilities
- Expanding the existing production tax credit from 6,000 to 8,000 megawatts, and permitting tax-exempt entities to allocate their available credits to private partners
- Permitting tax-exempt bonds to be used for public-private partnerships, which would allow POUs to issue tax-free, low-cost bonds for nuclear plants developed jointly with private interests
- Expanding federal regulatory risk insurance coverage from $2 billion to $6 billion (up to $500 million per reactor), which would further shield plant developers from costs associated with regulatory or legal delays

earmarked for the repository, has collected roughly $31 billion in waste-disposal fees through 2009. There is no mechanism other than investment returns on collections to fully fund the repository once reactors close.

The repository confers a variety of subsidies to the nuclear sector. First, despite its complexity and sizable investment, the repository is structured to operate on a break-even basis at best, with no required return on investment. Second, utilities do not have to pay any fee to secure repository capacity; in fact, they are allowed to defer payments for waste generated prior to the repository program's creation, at interest rates well below their cost of capital. Third, the significant risk of delays and cost overruns will be borne by taxpayers rather than the program's beneficiaries. Delays in the repository's opening have already triggered a rash of lawsuits and taxpayer-funded waste storage at reactor sites, at a cost between $12 billion and $50 billion.

- **Plant decommissioning.** While funds are collected during plant operation for decommissioning once the plant's life span has ended, reduced tax rates on nuclear decommissioning trust funds provide an annual subsidy to existing reactors of between $450 million and $1.1 billion per year. Meanwhile, concerns persist about whether the funds accrued will be sufficient to cover the costs; in 2009, the Nuclear Regulatory Commission (NRC) notified the operators of roughly one-quarter of the nation's reactor fleet about the potential for insufficient funding. We did not quantify the cost of this potential shortfall.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Historical subsidies to nuclear power have already resulted in hundreds of billions of dollars in costs paid by taxpayers and ratepayers. With escalating plant costs and more competitive power markets, the cost of repeating these failed policies will likely be even higher this time around. Of equal importance, however, is the fact that subsidies to nuclear power also carry significant opportunity costs for reducing global warming emissions because reactors are so expensive and require such long lead times to construct. In other words, massive subsidies designed to help underwrite the large-scale expansion of the nuclear industry will delay or diminish investments in less expensive abatement options.

Other energy technologies would be able to compete with nuclear power far more effectively if the government focused on creating an energy-neutral playing field rather than picking technology winners and losers. The policy choice to invest in nuclear also carries with it a risk unique to the nuclear fuel cycle: greatly exacerbating already thorny proliferation challenges as reactors and ancillary fuel-cycle facilities expand throughout the world.

As this report amply demonstrates, taxpayer subsidies to nuclear power have provided an indispensable foundation for the industry's existence, growth, and survival. But instead of reworking its business model to more effectively manage and internalize its operational and construction risks, the industry is pinning its hopes on a new wave of taxpayer subsidies to prop up a new generation of reactors.

Future choices about U.S. energy policy should be made with a full understanding of the hidden taxpayer costs now embedded in nuclear power. To accomplish this goal, we offer the following recommendations:

- **Reduce, not expand, subsidies to the nuclear power industry.** Federal involvement in energy markets should instead focus on encouraging firms involved in nuclear power—some of the largest corporations in the world—to create new models for internal risk pooling and to develop advanced power contracts that enable high-risk projects to move forward without additional taxpayer risk.
- **Award subsidies to low-carbon energy sources on the basis of a competitive bidding process across all competing technologies.** Subsidies

should be awarded to those approaches able to achieve emissions reductions at the lowest possible cost per unit of abatement—not on the basis of congressional earmarks for specific types of energy.

- **Modernize liability systems for nuclear power.** Liability systems should reflect current options in risk syndication, more robust requirements for the private sector, and more extensive testing of the current rules for excess risk concentration and counterparty risks. These steps are necessary to ensure coverage will actually be available when needed, and to send more accurate risk-related price signals to investors and power consumers.
- **Establish proper regulation and fee structures for uranium mining.** Policy reforms are needed to eliminate outdated tax subsidies, adopt market-level royalties for uranium mines on public lands, and establish more appropriate bonding regimes for land reclamation.
- **Adopt a more market-oriented approach to financing the Nuclear Waste Repository.** The government should require sizeable waste management deposits by the industry, a repository fee structure that earns a return on investment at least comparable to other large utility projects, and more equitable sharing of financial risks if additional delays occur.
- **Incorporate water pricing to allocate limited resources among competing demands, and integrate associated damages from large withdrawals.** The government should establish appropriate benchmarks for setting water prices that will be paid by utilities and other consumers, using a strategy that incorporates ecosystem damage as well as consumption-based charges.
- **Repeal decommissioning tax breaks and ensure greater transparency of nuclear decommissioning trusts (NDTs).** Eliminating existing tax breaks for NDTs would put nuclear power on a similar footing with other energy sources. More detailed and timely information on NDT funding and performance should be collected and publicized by the NRC.
- **Ensure that publicly owned utilities adopt appropriate risk assessment and asset management procedures.** POUs and relevant state regulatory agencies should review their internal procedures to be sure the financial and delivery risks of nuclear investments are appropriately compared with other options.
- **Roll back state construction-work-in-progress allowances and protect ratepayers against cost overruns by establishing clear limits on customer exposure.** States should also establish a refund mechanism for instances in which plant construction is cancelled after it has already begun.
- **Nuclear power should not be eligible for inclusion in a renewable portfolio standard.** Nuclear power is an established, mature technology with a long history of government support. Furthermore, nuclear plants are unique in their potential to cause catastrophic damage (due to accidents, sabotage, or terrorism); to produce very long-lived radioactive wastes; and to exacerbate nuclear proliferation.
- **Evaluate proliferation and terrorism as an externality of nuclear power.** The costs of preventing nuclear proliferation and terrorism should be recognized as negative externalities of civilian nuclear power, thoroughly evaluated, and integrated into economic assessments—just as global warming emissions are increasingly identified as a cost in the economics of coal-fired electricity.
- **Credit support for the nuclear fuel cycle via export credit agencies should explicitly integrate proliferation risks and require project-based credit screening.** Such support should require higher interest rates than those extended to other, less risky power projects, and include conditions on fuel-cycle investments to ensure the lending does not contribute to proliferation risks in the recipient country.

Nuclear Information and Resource Service

THE PEBBLE BED MODULAR REACTOR (PBMR)

THE PBMR: "OLD WINE IN A NEW BOTTLE"

The Pebble Bed Modular Reactor (PBMR) is being re-introduced in an industry effort to revive an all-but-moribund nuclear power technology. The PBMR's basic design concept, the high-temperature gas-cooled reactor (HTGR), has been commercially abandoned time and again without tangible benefit over the past thirty years in England, France, Germany and with the 1967 and 1989 closures of the Peach Bottom Unit 1 and Fort St. Vrain reactors in the United States. Small HTGR non-power research reactors currently operate in Japan and China. For as many years, the concept has been offered as an "inherently safe" design.

The current PBMR project is a hybrid of these past efforts and is piloted by an international conglomerate of U.S.-based Exelon Corporation (Commonwealth Edison, PECO Energy, and British Energy), British Nuclear Fuels Limited and South African-based ESKOM as "merchant" nuclear power plants. The consortium plans to begin the construction by 2002 of a full-size prototype of a 110 MW modular unit in Koeberg, South Africa. If successful, commercial operation would begin in 2006.

Exelon hopes to use this prototype to obtain a license through the Nuclear Regulatory Commission to begin construction of seven new reactors on an unspecified site in the U.S. by the summer of 2004. The PBMR is proposed as a standardized design that can be built in as little as two years, with multiple modular units combined onto a single site.

NO REACTOR CONTAINMENT BUILDING AND REDUCED SAFETY SYSTEMS CUT PBMR COSTS

Unlike light water reactors that use water and steam, the PBMR design would use pressurized helium heated in the reactor core to drive a series of turbine compressors that attach to an electrical generator. The helium is cycled to a recuperator to be cooled down and returned to cool the reactor while the waste heat is discharged to the environment. Designers claim there are no accident scenarios that would result in significant fuel damage and catastrophic release of radioactivity.

These industry safety claims rely on the heat resistant quality and integrity of the tennis ball-sized graphite fuel assemblies or "pebbles," 400,000 of which are continuously fed from a fuel silo through the reactor "little by little" to keep the reactor core only marginally critical. Each spherical fuel element has an inner graphite core embedded with thousands of smaller fuel particles of enriched uranium (up to 10 %) encapsulated in multi-layers of non-porous hardened carbon. The slow circulation of fuel through the reactor provides for a small core size that minimizes excess core reactivity and lowers power density, all of which is credited to safety.

However, so much credit is given to the integrity and quality control of the coated fuel pebbles to retain the radioactivity that no containment building is planned for the PBMR design. While the elimination of the containment building provides a significant cost savings for the utility—perhaps making the design economically feasible—the trade-off is public health and safety.

The protective containment building also is nixed because it would hinder the design's passive cooling feature of the reactor core through natural convection (air cooling). Exelon also proposes a dramatic reduction in additional reactor safety systems and procedures (i.e. no emergency core cooling system and a reduced one-half mile emergency planning zone as compared to a 10-mile emergency planning zone for light water reactors) to provide for further reducing PBMR construction and operation costs.

To date, however, Exelon has not submitted to the Nuclear Regulatory Commission descriptions of challenges that could lead to a radiological accident such as a fire that ignites the combustible graphite loaded into the core. Fire and smoke then become the transport vehicle for radioactivity released to the environment from damaged fuel.

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In addition, the lack of containment would require 100%-perfect quality control in the manufacture of the fuel pellets—an impossible goal. Imperfections in fuel pellet manufacture could lead to higher radiation releases during normal operation than is the case with conventional reactors.

"INHERENTLY SAFE" GERMAN PBMR COVERS UP RADIATION ACCIDENT AND SHUTS DOWN

As Dr. Edward Teller, the father of the H-bomb said, "Sooner or later a fool will prove greater than the proof even in a foolproof system." Accidents can and do happen in the inherently dangerous business of splitting the atom. Human error occurs at every level of development, construction and operation of the process. Material and component failures along with aging can break down or defeat operational and safety systems.

In 1985, the experimental THTR-300 PBMR on the Ruhr in Hamm-Uentrop, Germany was also offered as accident proof--with the same promise of an indestructible carbon fuel cladding capable of retaining all generated radioactivity. Following the April 26, 1986 Chernobyl nuclear reactor accident and graphite fire in Ukraine, the West German government revealed that on May 4, the 300-megawatt PBMR at Hamm released radiation after one of its spherical fuel pebbles became lodged in the pipe feeding the fuel to the reactor. Operator actions during the event caused damage to the fuel cladding.

Radioactivity was released with the escaping helium and radioactive fallout was deposited as far as two kilometers from the reactor. The fallout in the region was high enough to initially be blamed on Chernobyl. Government officials were then alerted by scientists in Freiburg who reported that as much as 70 % of the region's contamination was not of the type of radiation leaking hundreds of miles away in Ukraine. Dismayed by an attempt to conceal the reactor malfunction and confronted with mounting public pressure in light of the Chernobyl accident only days prior, the state ordered the reactor to close pending a design review.

Continuing technical problems including a lack of quality control resulting in damage to unused fuel pebbles and radiation-induced bolt head failures in the reactor's gas channels resulted in the unit's closure in late 1988. Citing doubts about reliability, the government refused to further subsidize utility funding and instead approved plans for decommissioning the reactor.

NUCLEAR WASTE REMAINS INTRINSICALLY DANGEROUS

A single 110-megawatt PBMR will produce 2.5 million irradiated fuel elements during a 40-year operational cycle. Nuclear waste remains dangerous over geological spans of time and a threat to life from radioactive contamination would persist long after a PBMR has closed. The health and environmental uncertainties associated with a historically mismanaged radioactive legacy from continued operation of nuclear technology is yet another reason the public will not accept the PBMR.—Paul Gunter, March 2001

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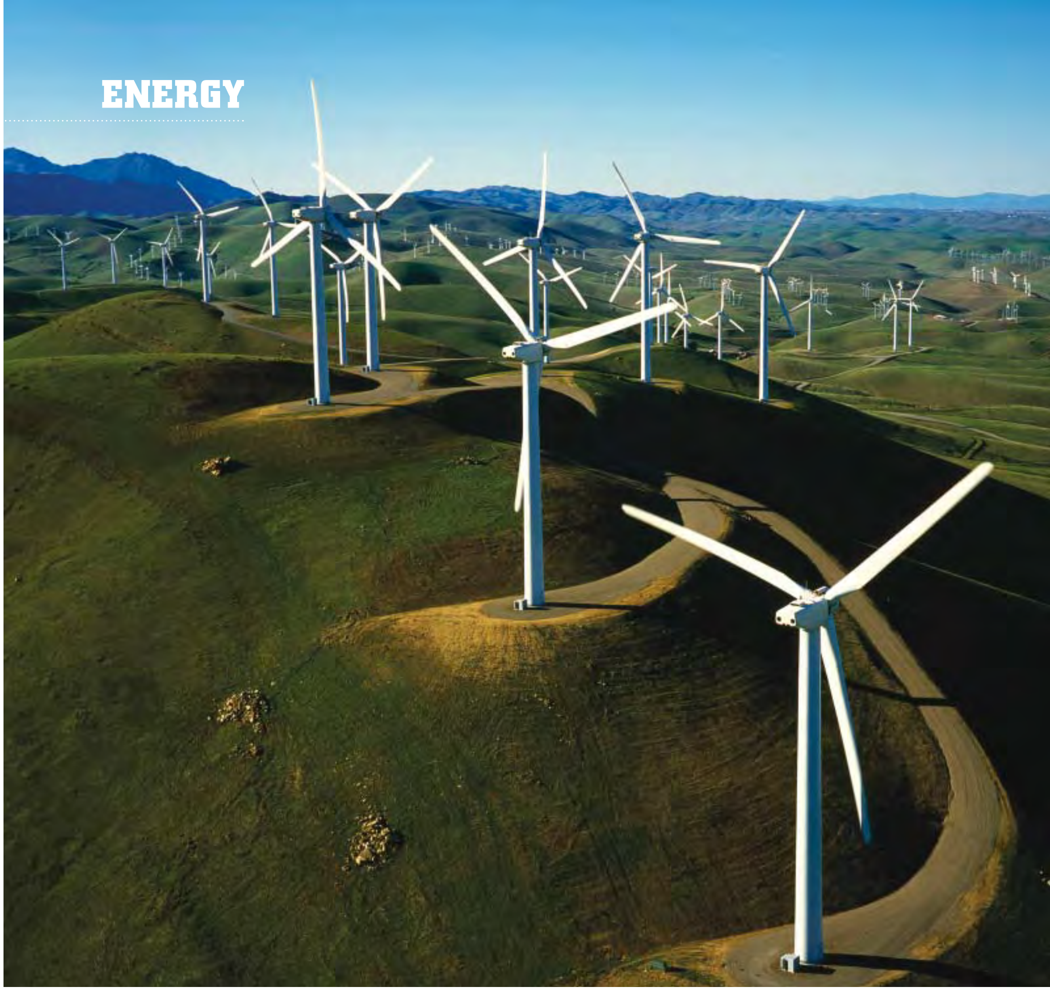
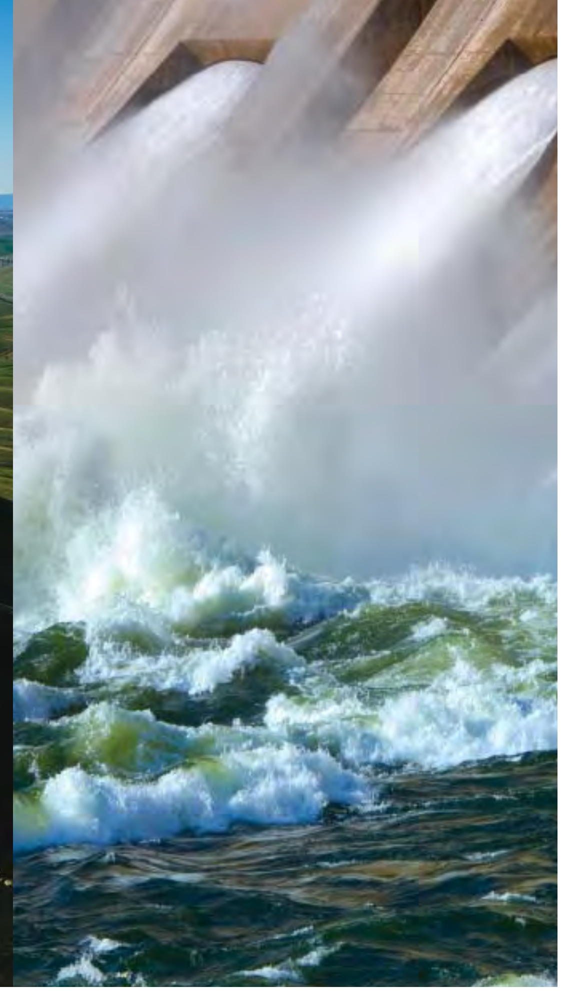




A PATH TO SUSTAINABLE ENERGY BY 2030

Wind, water and solar technologies can provide 100 percent of the world's energy, eliminating all fossil fuels.
HERE'S HOW

By Mark Z. Jacobson and Mark A. Delucchi

In December leaders from around the world will meet in Copenhagen to try to agree on cutting back greenhouse gas emissions for decades to come. The most effective step to implement that goal would be a massive shift away from fossil fuels to clean, renewable energy sources. If leaders can have confidence that such a transformation is possible, they might commit to an historic agreement. We think they can.

A year ago former vice president Al Gore threw down a gauntlet: to repower America with 100 percent carbon-free electricity within 10 years. As the two of us started to evaluate the feasibility of such a change, we took on an even larger challenge: to determine how 100 percent of the world's energy, for *all* purposes, could be supplied by wind, water and solar resources, by as early as 2030. Our plan is presented here.

Scientists have been building to this moment for at least a decade, analyzing various pieces of the challenge. Most recently, a 2009 Stanford University study ranked energy systems according to their impacts on global warming, pollution, water supply, land use, wildlife and other concerns. The very best options were wind, solar, geothermal, tidal and hydroelectric power—all of which are driven by wind, water or sunlight (referred to as WWS). Nuclear power, coal with carbon capture, and ethanol were all poorer options, as were oil and natural gas. The study also found that battery-electric vehicles and hydrogen fuel-cell vehicles recharged by WWS options would largely eliminate pollution from the transportation sector.

Our plan calls for millions of wind turbines, water machines and solar installations. The numbers are large, but the scale is not an insurmountable hurdle; society has achieved massive

transformations before. During World War II, the U.S. retooled automobile factories to produce 300,000 aircraft, and other countries produced 486,000 more. In 1956 the U.S. began building the Interstate Highway System, which after 35 years extended for 47,000 miles, changing commerce and society.

Is it feasible to transform the world's energy systems? Could it be accomplished in two decades? The answers depend on the technologies chosen, the availability of critical materials, and economic and political factors.

Clean Technologies Only

Renewable energy comes from enticing sources: wind, which also produces waves; water, which includes hydroelectric, tidal and geothermal energy (water heated by hot underground rock); and sun, which includes photovoltaics and solar power plants that focus sunlight to heat a fluid that drives a turbine to generate electricity. Our plan includes only technologies that work or are close to working today on a large scale, rather than those that may exist 20 or 30 years from now.

To ensure that our system remains clean, we consider only technologies that have near-zero emissions of greenhouse gases and air pollutants over their entire life cycle, including construction, operation and decommissioning. For example, when burned in vehicles, even the most ecologically acceptable sources of ethanol create air pollution that will cause the same mortality level as when gasoline is burned. Nuclear power results in up to 25 times more carbon emissions than wind energy, when reactor construction and uranium refining and transport are considered. Carbon capture and sequestration technology can reduce carbon dioxide emissions from coal-fired power plants but will *increase* air pollutants and will extend all the other deleterious effects of coal mining, transport and processing, because more coal must be burned to power the capture and storage steps. Similarly, we consider only technologies that do not present significant waste disposal or terrorism risks.

In our plan, WWS will supply electric power for heating and transportation—industries that will have to revamp if the world has any hope of slowing climate change. We have assumed that most fossil-fuel heating (as well as ovens and stoves) can be replaced by electric systems and that most fossil-fuel transportation can be replaced by battery and fuel-cell vehicles. Hydrogen, produced by using WWS electricity to split water (electrolysis), would power fuel cells and be burned in airplanes and by industry.

HO/REUTERS/CORBIS (*solar panels*)

KEY CONCEPTS

- Supplies of wind and solar energy on accessible land dwarf the energy consumed by people around the globe.
- The authors' plan calls for 3.8 million large wind turbines, 90,000 solar plants, and numerous geothermal, tidal and rooftop photovoltaic installations worldwide.
- The cost of generating and transmitting power would be less than the projected cost per kilowatt-hour for fossil-fuel and nuclear power.
- Shortages of a few specialty materials, along with lack of political will, loom as the greatest obstacles.

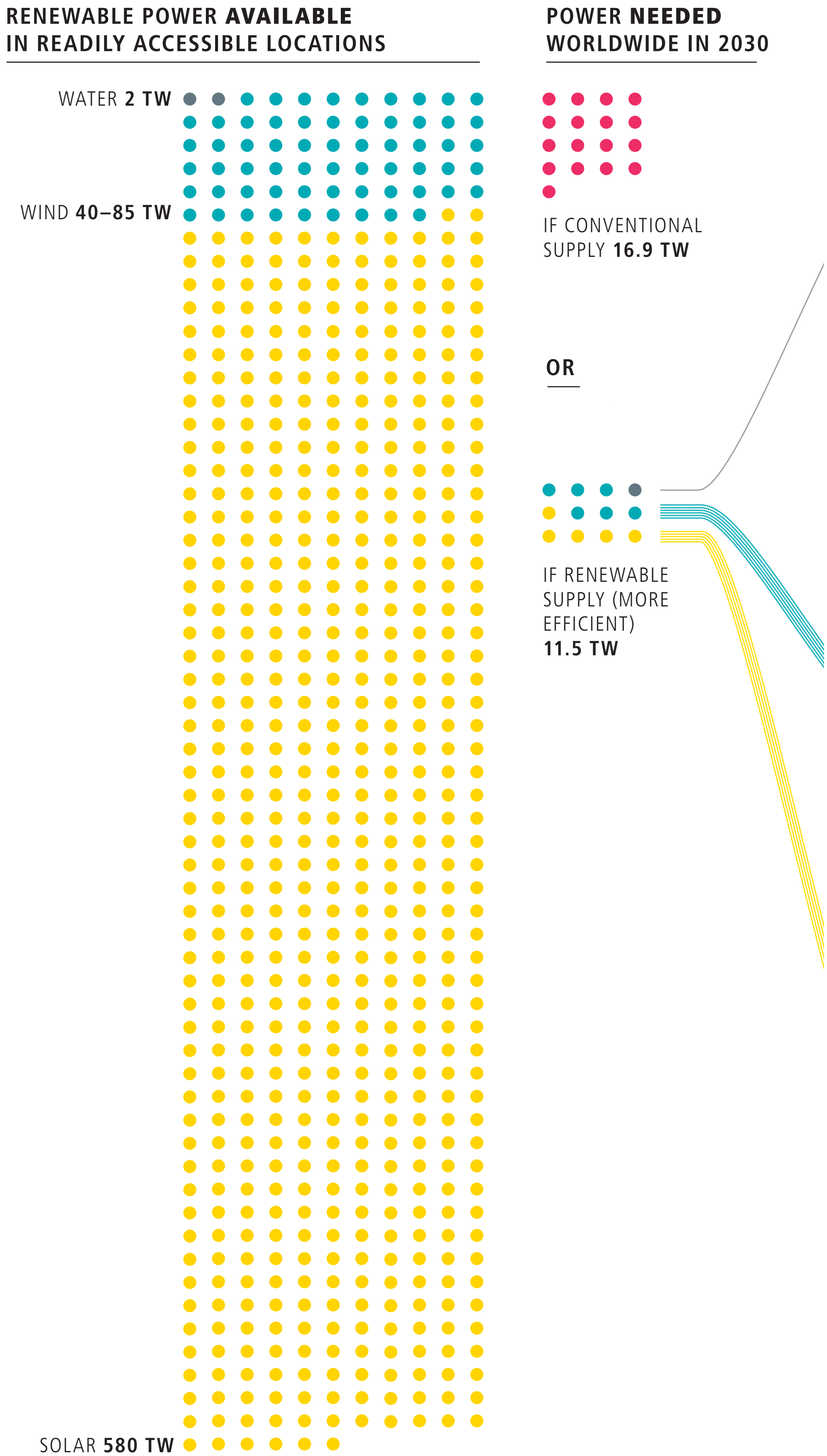
—The Editors

Plenty of Supply

Today the maximum power consumed worldwide at any given moment is about 12.5 trillion watts (terawatts, or TW), according to the U.S. Energy Information Administration. The agency projects that in 2030 the world will require 16.9 TW of power as global population and living standards rise, with about 2.8 TW in the U.S. The mix of sources is similar to today's, heavily dependent on fossil fuels. If, however, the planet were powered entirely by WWS, with no fossil-fuel or biomass combustion, an intriguing savings would occur. Global power demand would be only 11.5 TW, and U.S. demand would be 1.8 TW. That decline occurs because, in most cases, electrification is a more efficient way to use energy. For example, only 17 to 20 percent of the energy in gasoline is used to move a vehicle (the rest is wasted as heat), whereas 75 to 86 percent of the electricity delivered to an electric vehicle goes into motion.

Even if demand did rise to 16.9 TW, WWS sources could provide far more power. Detailed studies by us and others indicate that energy from the wind, worldwide, is about 1,700 TW. Solar, alone, offers 6,500 TW. Of course, wind and sun out in the open seas, over high mountains and across protected regions would not be available. If we subtract these and low-wind areas not likely to be developed, we are still left with 40 to 85 TW for wind and 580 TW for solar, each far beyond future human demand. Yet currently we generate only 0.02 TW of wind power and 0.008 TW of solar. These sources hold an incredible amount of untapped potential.

The other WWS technologies will help create a flexible range of options. Although all the sources can expand greatly, for practical reasons, wave power can be extracted only near coastal areas. Many geothermal sources are too deep to be tapped economically. And even though hydroelectric power now exceeds all other WWS sources, most of the suitable large reservoirs are already in use.



MW – MEGAWATT = 1 MILLION WATTS
GW – GIGAWATT = 1 BILLION WATTS
TW – TERAWATT = 1 TRILLION WATTS

The Editors welcome responses to this article. To comment and to see more detailed calculations, go to **www.ScientificAmerican.com/sustainable-energy**

RENEWABLE INSTALLATIONS REQUIRED WORLDWIDE

WATER **1.1 TW** (9% OF SUPPLY)

490,000
TIDAL TURBINES – 1 MW* – <1% IN PLACE
*size of unit

5,350
GEOTHERMAL PLANTS – 100 MW – 2% IN PLACE

900
HYDROELECTRIC PLANTS – 1,300 MW – 70% IN PLACE

WIND **5.8 TW** (51% OF SUPPLY)

3,800,000
WIND TURBINES – 5 MW – 1% IN PLACE

720,000
WAVE CONVERTERS* – 0.75 MW – <1% IN PLACE
*wind drives waves

SOLAR **4.6 TW** (40% OF SUPPLY)

1,700,000,000
ROOFTOP PHOTOVOLTAIC SYSTEMS* – 0.003 MW – <1% IN PLACE
*sized for a modest house; a commercial roof might have dozens of systems

49,000
CONCENTRATED SOLAR POWER PLANTS – 300 MW – <1% IN PLACE

40,000
PHOTOVOLTAIC POWER PLANTS – 300 MW – <1% IN PLACE

The Plan: Power Plants Required

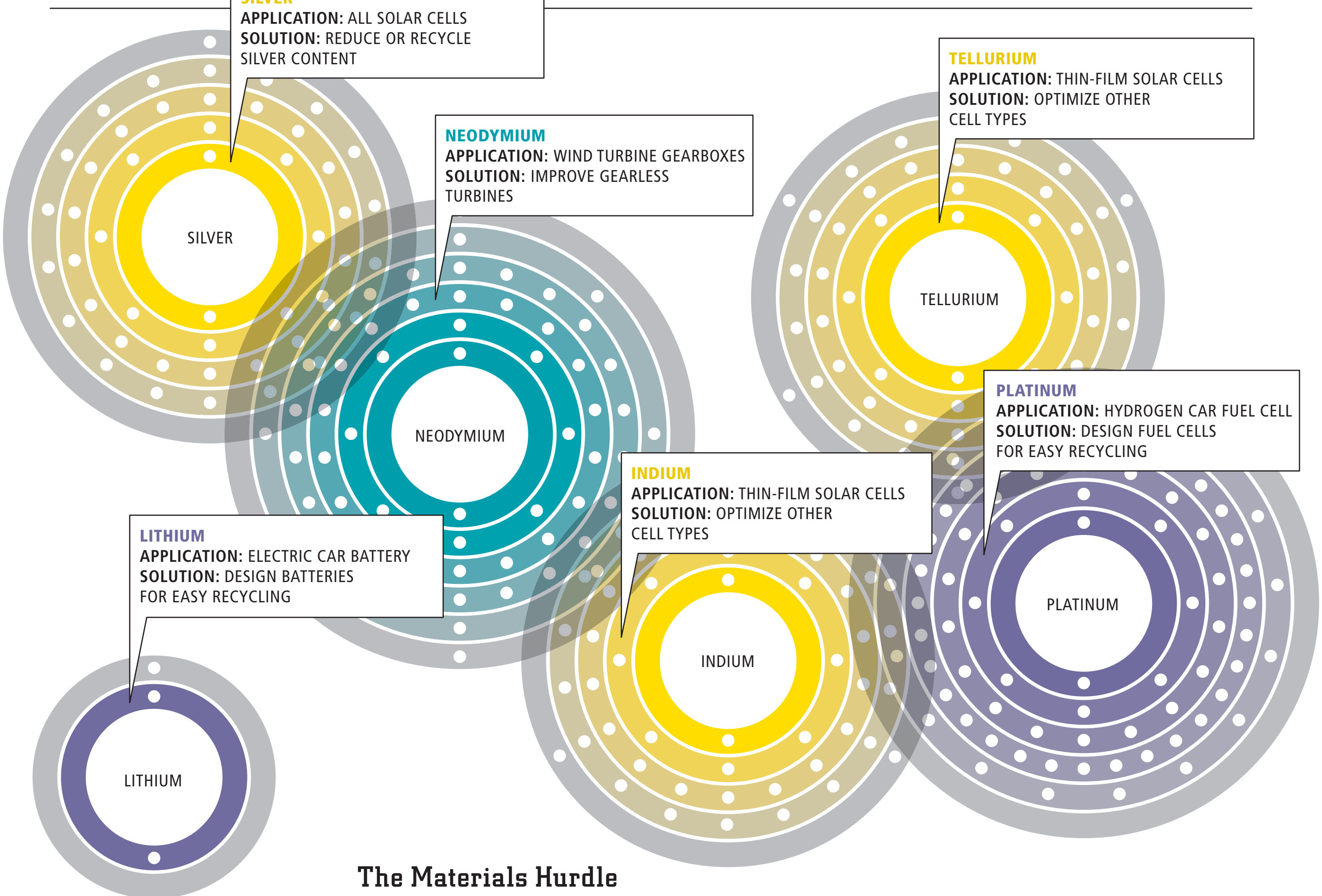
Clearly, enough renewable energy exists. How, then, would we transition to a new infrastructure to provide the world with 11.5 TW? We have chosen a mix of technologies emphasizing wind and solar, with about 9 percent of demand met by mature water-related methods. (Other combinations of wind and solar could be as successful.)

Wind supplies 51 percent of the demand, provided by 3.8 million large wind turbines (each rated at five megawatts) worldwide. Although that quantity may sound enormous, it is interesting to note that the world manufactures 73 million cars and light trucks *every year.* Another 40 percent of the power comes from photovoltaics and concentrated solar plants, with about 30 percent of the photovoltaic output from rooftop panels on homes and commercial buildings. About 89,000 photovoltaic and concentrated solar power plants, averaging 300 megawatts apiece, would be needed. Our mix also includes 900 hydroelectric stations worldwide, 70 percent of which are already in place.

Only about 0.8 percent of the wind base is installed today. The worldwide footprint of the 3.8 million turbines would be less than 50 square kilometers (smaller than Manhattan). When the needed spacing between them is figured, they would occupy about 1 percent of the earth's land, but the empty space among turbines could be used for agriculture or ranching or as open land or ocean. The nonrooftop photovoltaics and concentrated solar plants would occupy about 0.33 percent of the planet's land. Building such an extensive infrastructure will take time. But so did the current power plant network. And remember that if we stick with fossil fuels, demand by 2030 will rise to 16.9 TW, requiring about 13,000 large new coal plants, which themselves would occupy a lot more land, as would the mining to supply them.

CATALOGTREE (*illustrations*); NICHOLAS EVELEIGH *Getty Images* (*plug*)

POSSIBLE MATERIALS SHORTAGES



The Materials Hurdle

The scale of the WWS infrastructure is not a barrier. But a few materials needed to build it could be scarce or subject to price manipulation.

Enough concrete and steel exist for the millions of wind turbines, and both those commodities are fully recyclable. The most problematic materials may be rare-earth metals such as neodymium used in turbine gearboxes. Although the metals are not in short supply, the low-cost sources are concentrated in China, so countries such as the U.S. could be trading dependence on Middle Eastern oil for dependence on Far Eastern metals. Manufacturers are moving toward gearless turbines, however, so that limitation may become moot.

Photovoltaic cells rely on amorphous or crystalline silicon, cadmium telluride, or copper indium selenide and sulfide. Limited supplies of tellurium and indium could reduce the prospects for some types of thin-film solar cells, though not for all; the other types might be able to take up the slack. Large-scale production could be restricted by the silver that cells require, but finding ways to reduce the silver content could tackle that hurdle. Recycling parts from old cells could ameliorate material difficulties as well.

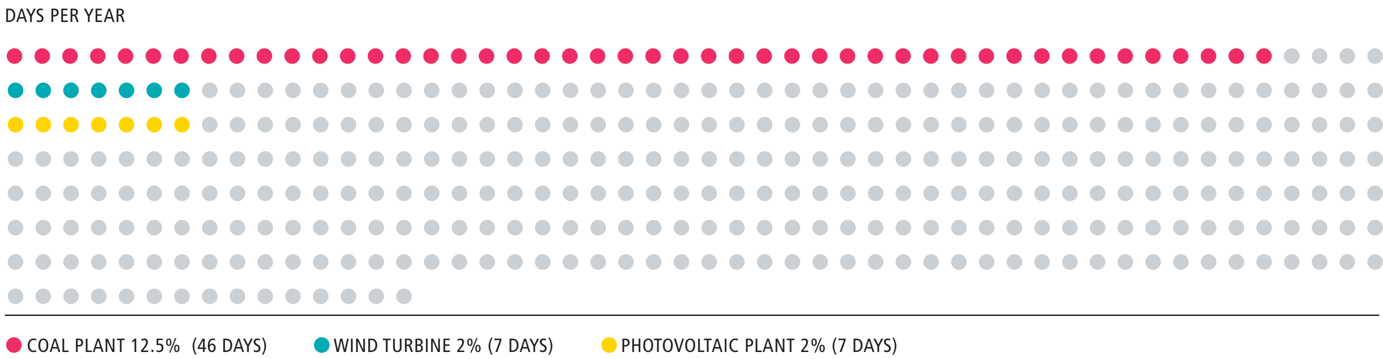
Three components could pose challenges for building millions of electric vehicles: rare-earth metals for electric motors, lithium for lithium-ion batteries and platinum for fuel cells. More than half the world's lithium reserves lie in Bolivia and Chile. That concentration, combined with rapidly growing demand, could raise prices significantly. More problematic is the claim by Meridian International Research that not enough economically recoverable lithium exists to build anywhere near the number of batteries needed in a global electric-vehicle economy. Recycling could change the equation, but the economics of recycling depend in part on whether batteries are made with easy recyclability in mind, an issue the industry is aware of. The long-term use of platinum also depends on recycling; current available reserves would sustain annual production of 20 million fuel-cell vehicles, along with existing industrial uses, for fewer than 100 years.

[THE AUTHORS]

Mark Z. Jacobson is professor of civil and environmental engineering at Stanford University and director of the Atmosphere/Energy Program there. He develops computer models to study the effects of energy technologies and their emissions on climate and air pollution. Mark A. Delucchi is a research scientist at the Institute of Transportation Studies at the University of California, Davis. He focuses on energy, environmental and economic analyses of advanced, sustainable transportation fuels, vehicles and systems.

CATALOGTREE (*illustration*); COURTESY OF MARK Z. JACOBSON (*Jacobson*); COURTESY OF KAREN DELUCCHI (*Delucchi*)

AVERAGE DOWNTIME FOR ANNUAL MAINTENANCE



Smart Mix for Reliability

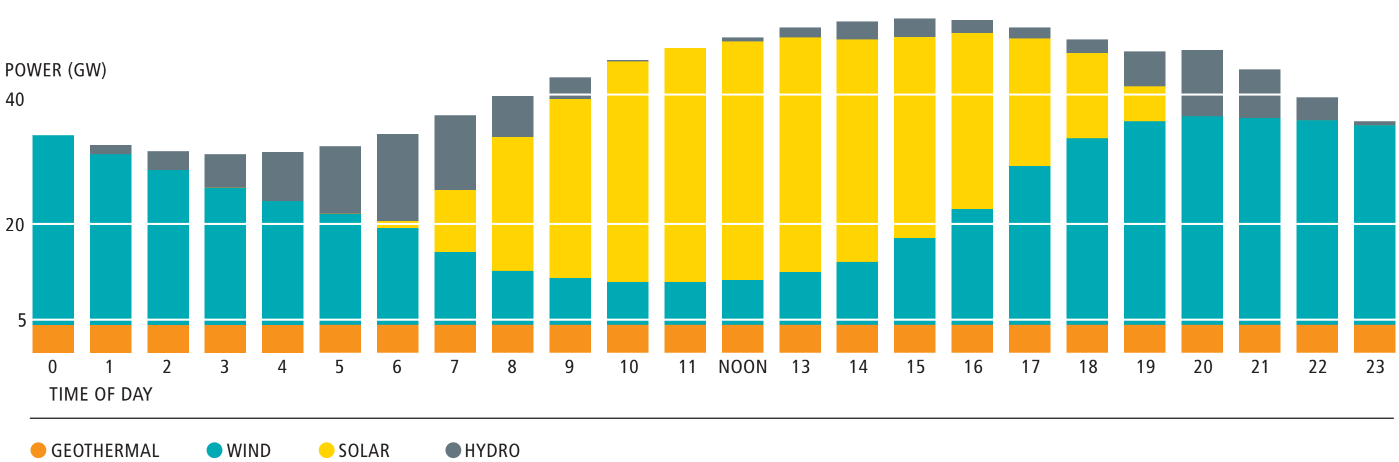
A new infrastructure must provide energy on demand at least as reliably as the existing infrastructure. WWS technologies generally suffer less downtime than traditional sources. The average U.S. coal plant is offline 12.5 percent of the year for scheduled and unscheduled maintenance. Modern wind turbines have a down time of less than 2 percent on land and less than 5 percent at sea. Photovoltaic systems are also at less than 2 percent. Moreover, when an individual wind, solar or wave device is down, only a small fraction of production is affected; when a coal, nuclear or natural gas plant goes offline, a large chunk of generation is lost.

The main WWS challenge is that the wind does not always blow and the sun does not always shine in a given location. Intermittency problems can be mitigated by a smart balance of sources, such as generating a base supply from steady geothermal or tidal power, relying on wind at night when it is often plentiful, using solar by day and turning to a reliable source such as hydroelectric that can be turned on and off quickly to smooth out supply or meet peak demand. For example, interconnecting wind farms that are only 100 to 200 miles apart can compensate for hours of zero power at any one farm should the wind not be blowing there. Also helpful is interconnecting geographically dispersed sources so they can back up one another, installing smart electric meters in homes that automatically recharge electric vehicles when demand is low and building facilities that store power for later use.

Because the wind often blows during stormy conditions when the sun does not shine and the sun often shines on calm days with little wind, combining wind and solar can go a long way toward meeting demand, especially when geothermal provides a steady base and hydroelectric can be called on to fill in the gaps.

▼ CALIFORNIA CASE STUDY: To show the power of combining resources, Graeme Hoste of Stanford University recently calculated how a mix of four renewable sources, in 2020, could generate 100 percent of California's electricity around the clock, on a typical July day. The hydroelectric capacity needed is already in place.

CLEAN ELECTRICITY 24/7



CATALOGTREE

As Cheap as Coal

The mix of WWS sources in our plan can reliably supply the residential, commercial, industrial and transportation sectors. The logical next question is whether the power would be affordable. For each technology, we calculated how much it would cost a producer to generate power and transmit it across the grid. We included the annualized cost of capital, land, operations, maintenance, energy storage to help offset intermittent supply, and transmission. Today the cost of wind, geothermal and hydroelectric are all less than seven cents a kilowatt-hour (¢/kWh); wave and solar are higher. But by 2020 and beyond wind, wave and hydro are expected to be 4¢/kWh or less.

For comparison, the average cost in the U.S. in 2007 of conventional power generation and transmission was about 7¢/kWh, and it is projected to be 8¢/kWh in 2020. Power from wind turbines, for example, already costs about the same or less than it does from a new coal or natural gas plant, and in the future wind power is expected to be the least costly of all options. The competitive cost of wind has made it the second-largest source of new electric power generation in the U.S. for the past three years, behind natural gas and ahead of coal.

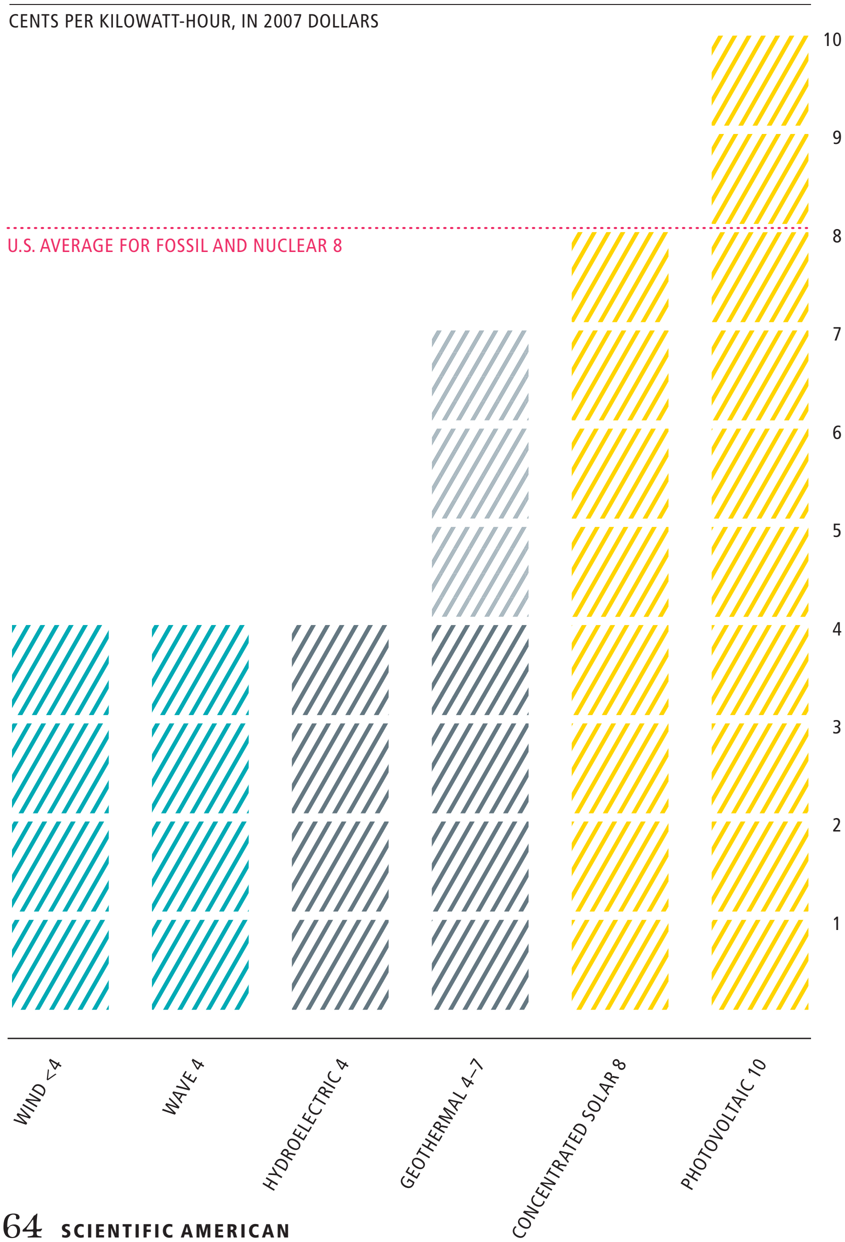
Solar power is relatively expensive now but should be competitive as early as 2020. A careful analysis by Vasilis Fthenakis of Brookhaven National Laboratory indicates that within 10 years, photovoltaic system costs could drop to about 10¢/kWh, including long-distance transmission and the cost of compressed-air storage of power for use at night. The same analysis estimates that concentrated solar power systems with enough thermal storage to generate electricity 24 hours a day in spring, summer and fall could deliver electricity at 10¢/kWh or less.

Transportation in a WWS world will be driven by batteries or fuel cells, so we should compare the economics of these electric vehicles with that of internal-combustion-engine vehicles. Detailed analyses by one of us (Delucchi) and Tim Lipman of the University of California, Berkeley, have indicated that mass-produced electric vehicles with advanced lithium-ion or nickel metal-hydride batteries could have a full lifetime cost per mile (including battery replacements) that is comparable with that of a gasoline vehicle, when gasoline sells for more than $2 a gallon.

When the so-called externality costs (the monetary value of damages to human health, the environment and climate) of fossil-fuel generation are taken into account, WWS technologies become even more cost-competitive.

Overall construction cost for a WWS system might be on the order of $100 trillion worldwide, over 20 years, not including transmission. But this is not money handed out by governments or consumers. It is investment that is paid back through the sale of electricity and energy. And again, relying on traditional sources would raise output from 12.5 to 16.9 TW, requiring thousands more of those plants, costing roughly $10 trillion, not to mention tens of trillions of dollars more in health, environmental and security costs. The WWS plan gives the world a new, clean, efficient energy system rather than an old, dirty, inefficient one.

COST TO GENERATE AND TRANSMIT POWER IN 2020



CATALOGTREE

▲ **COAL MINERS and other fossil-fuel workers, unions and lobbyists are likely to resist a transformation to clean energy; political leaders will have to champion the cause.**

JEFF GENTNER *AP Photo* (*protesters*); DON FARRALL *Getty Images* (*coal*)

Political Will

Our analyses strongly suggest that the costs of WWS will become competitive with traditional sources. In the interim, however, certain forms of WWS power will be significantly more costly than fossil power. Some combination of WWS subsidies and carbon taxes would thus be needed for a time. A feed-in tariff (FIT) program to cover the difference between generation cost and wholesale electricity prices is especially effective at scaling-up new technologies. Combining FITs with a so-called declining clock auction, in which the right to sell power to the grid goes to the lowest bidders, provides continuing incentive for WWS developers to lower costs. As that happens, FITs can be phased out. FITs have been implemented in a number of European countries and a few U.S. states and have been quite successful in stimulating solar power in Germany.

Taxing fossil fuels or their use to reflect their environmental damages also makes sense. But at a minimum, existing subsidies for fossil energy, such as tax benefits for exploration and extraction, should be eliminated to level the playing field. Misguided promotion of alternatives that are less desirable than WWS power, such as farm and production subsidies for biofuels, should also be ended, because it delays deployment of cleaner systems. For their part, legislators crafting policy must find ways to resist lobbying by the entrenched energy industries.

Finally, each nation needs to be willing to invest in a robust, long-distance transmission system that can carry large quantities of WWS power from remote regions where it is often greatest—such as the Great Plains for wind and the desert Southwest for solar in the U.S.—to centers of consumption, typically cities. Reducing consumer demand during peak usage periods also requires a smart grid that gives generators and consumers much more control over electricity usage hour by hour.

A large-scale wind, water and solar energy system can reliably supply the world's needs, significantly benefiting climate, air quality, water quality, ecology and energy security. As we have shown, the obstacles are primarily political, not technical. A combination of feed-in tariffs plus incentives for providers to reduce costs, elimination of fossil subsidies and an intelligently expanded grid could be enough to ensure rapid deployment. Of course, changes in the real-world power and transportation industries will have to overcome sunk investments in existing infrastructure. But with sensible policies, nations could set a goal of generating 25 percent of their new energy supply with WWS sources in 10 to 15 years and almost 100 percent of new supply in 20 to 30 years. With extremely aggressive policies, all existing fossil-fuel capacity could theoretically be retired and replaced in the same period, but with more modest and likely policies full replacement may take 40 to 50 years. Either way, clear leadership is needed, or else nations will keep trying technologies promoted by industries rather than vetted by scientists.

A decade ago it was not clear that a global WWS system would be technically or economically feasible. Having shown that it is, we hope global leaders can figure out how to make WWS power politically feasible as well. They can start by committing to meaningful climate and renewable energy goals now. ■

➥ MORE TO EXPLORE

Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. S. Pacala and R. Socolow in *Science*, Vol. 305, pages 968–972; 2004.

Evaluation of Global Wind Power. Cristina L. Archer and Mark Z. Jacobson in *Journal of Geophysical Research—Atmospheres,* Vol. 110, D12110; June 30, 2005.

Going Completely Renewable: Is It Possible (Let Alone Desirable)? B. K. Sovacool and C. Watts in *The Electricity Journal,* Vol. 22, No. 4, pages 95–111; 2009.

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The Technical, Geographical, and Economic Feasibility for Solar Energy to Supply the Energy Needs of the U.S. V. Fthenakis, J. E. Mason and K. Zweibel in *Energy Policy,* Vol. 37, pages 387–399; 2009.

January 16, 2014
HUFF POST GREEN

With Nuclear Power, "No Acts of God Can Be Permitted"

As heroic workers and soldiers strive to save stricken Japan from a new horror--radioactive fallout--some truths known for 40 years bear repeating.

An earthquake-and-tsunami zone crowded with 127 million people is an un-wise place for 54 reactors. The 1960s design of five Fukushima-I reactors has the smallest safety margin and probably can't contain 90% of melt-downs. The U.S. has 6 identical and 17 very similar plants.

Every currently operating light-water reactor, if deprived of power and cooling water, can melt down. Fukushima had 8-hour battery reserves, but fuel has melted in three reactors. Most U.S. reactors get in trouble after 4 hours. Some have had shorter blackouts. Much longer ones could happen.

Overheated fuel risks hydrogen or steam explosions that damage equipment and contaminate the whole site--so clustering many reactors together (to save money) can make failure at one reactor cascade to the rest.

Nuclear power is uniquely unforgiving: as Swedish Nobel physicist Hannes Alfvén said, "No acts of God can be permitted." Fallible people have created its half-century history of a few calamities, a steady stream of worrying incidents, and many near-misses. America has been lucky so far. Had Three Mile Island's containment dome not been built double-strength because it was under an airport landing path, it may not have withstood the 1979 accident's hydrogen explosion. In 2002, Ohio's Davis-Besse reactor was luckily caught just before its massive pressure-vessel lid rusted through.

Regulators haven't resolved these or other key safety issues, such as terrorist threats to reactors, lest they disrupt a powerful industry. U.S. regulation is not clearly better than Japanese regulation, nor more transparent: industry-friendly rules bar the American public from meaningful participation. Many Presidents' nuclear boosterism also discourages inquiry and dissent.

Nuclear-promoting regulators inspire even less confidence. The International Atomic Energy Agency's 2005 estimate of about 4,000 Chernobyl deaths contrasts with a rigorous 2009 review of 5,000 mainly Slavic-language scientific papers the IAEA overlooked. It found deaths approaching a million through 2004, nearly 170,000 of them in North America. The total toll now exceeds a million, plus a half-trillion dollars' economic damage. The fallout reached four continents, just as the jet stream could swiftly carry Fukushima fallout.

Fukushima I-4's spent fuel alone, while in the reactor, had produced (over years, not in an instant) more than a hundred times more fission energy and hence radioactivity than both 1945 atomic bombs. If that already-damaged fuel keeps overheating, it may melt or burn, releasing into the air things like cesium-137 and strontium-90, which take several centuries to decay a millionfold. Unit 3's fuel is spiked with plutonium, which takes 482,000 years.

Nuclear power is the only energy source where mishap or malice can kill so many people so far away; the only one whose ingredients can help make and hide nuclear bombs; the only climate solution that substitutes proliferation, accident, and high-level radioactive waste dangers. Indeed, nuclear plants are so slow and costly to build that they reduce and retard climate protection.

Here's how. Each dollar spent on a new reactor buys about 2-10 times less carbon savings, 20-40 times slower, than spending that dollar on the cheaper, faster, safer solutions that make nuclear power unnecessary and uneconomic: efficient use of electricity, making heat and power together in factories or buildings ("cogeneration"), and renewable energy. The last two made 18% of the world's 2009 electricity, nuclear 13%, reversing their 2000 shares--and made over 90% of the world's additional electricity in 2008.

Those smarter choices are sweeping the global energy market. Half the world's new generating capacity in 2008 and 2009 was renewable. In 2010, renewables except big hydro dams won $151 billion of private investment and added over 50 billion watts (70% the total capacity of all 23 Fukushima-style U.S. reactors) while nuclear got zero private investment and kept losing capacity. Supposedly unreliable windpower made 43-52% of four German states' total 2010 electricity. Non-nuclear Denmark, 21% wind-powered, plans to get entirely off fossil fuels. Hawai'i plans 70% renewables by 2025.

In contrast, of the 66 nuclear units worldwide officially listed as "under construction" at the end of 2010, 12 had been so listed for over 20 years, 45 had no official startup date, half were late, all 66 were in centrally planned power systems--50 of those in just four (China, India, Russia, South Korea)--and zero were free-market purchases. Since 2007, nuclear growth has added less annual output than just the costliest renewable--solar power --and will probably never catch up. While inherently safe renewable competitors are walloping both nuclear and coal plants in the marketplace and keep getting dramatically cheaper, nuclear costs keep soaring, and with greater safety precautions would go even higher. Tokyo Electric Co., just recovering from $10-20 billion in 2007 earthquake costs at its other big nuclear complex, now faces an even more ruinous Fukushima bill.

Since 2005, new U.S. reactors (if any) have been 100+% subsidized--yet they couldn't raise a cent of private capital, because they have no business case. They cost 2-3 times as much as new windpower, and by the time you could build a reactor, it couldn't even beat solar power. Competitive renewables, cogeneration, and efficient use can displace all U.S. coal power more than 23 times over--leaving ample room to replace nuclear power's half-as-big-as-coal contribution too--but we need to do it just once. Yet the nuclear industry demands ever more lavish subsidies, and its lobbyists hold all other energy efforts hostage for tens of billions in added ransom, with no limit.

Japan, for its size, is even richer than America in benign, ample, but long-neglected energy choices. Perhaps this tragedy will call Japan to global leadership into a post-nuclear world. And before America suffers its own Fukushima, it too should ask, not whether unfinanceably costly new reactors are safe, but why build any more, and why keep running unsafe ones. China has suspended reactor approvals. Germany just shut down the oldest 41% of its nuclear capacity for study. America's nuclear lobby says it can't happen here, so pile on lavish new subsidies.

A durable myth claims Three Mile Island halted U.S. nuclear orders. Actually they stopped over a year before--dead of an incurable attack of market forces. No doubt when nuclear power's collapse in the global marketplace, already years old, is finally acknowledged, it will be blamed on Fukushima. While we pray for the best in Japan today, let us hope its people's sacrifice will help speed the world to a safer, more competitive energy future.

Physicist Amory Lovins consults on energy to business and government leaders worldwide. He's written 31 books and over 450 papers, and received the Blue Planet, Volvo, Onassis, Nissan, Shingo, Zayed, and Mitchell Prizes, MacArthur and Ashoka Fellowships, 11 honorary doctorates, and the Heinz, Lindbergh, Right Livelihood, National Design, and World Technology Awards. He's an honorary U.S. architect, a Swedish engineering academician, and a former Oxford don, and has taught at nine universities, most recently Stanford. His RMI team's autumn 2011 book Reinventing Fire describes business-led pathways for a vibrant U.S. economy that by 2050 needs no oil, coal, or nuclear power to provide clean and resilient energy with superior economics.

The World Nuclear Industry Status Report 2013

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Foreword by Peter A. Bradford

Paris, London, July 2013

A
MYCLE SCHNEIDER CONSULTING
Project

The nuclear share in the world's power generation declined steadily from a historic peak of 17 percent in 1993 to about 10 percent in 2012. Nuclear power's share of global commercial primary energy production plunged to 4.5 percent, a level last seen in 1984.[9] Only one country, the Czech Republic, reached its record nuclear contribution to the electricity mix in 2012.

Age. In the absence of major new-build programs, the unit-weighted average age of the world nuclear reactor fleet continues to increase and in mid-2013 stands at 28 years. Over 190 units (45 percent of total) have operated for 30 years of which 44 have run for 40 years or more.

Construction. Fourteen countries are currently building nuclear power plants, one more than a year ago as the United Arab Emirates (UAE) started construction at Barrakah. The UAE is the first new country in 27 years to have started building a commercial nuclear power plant.

As of July 2013, 66 reactors are under construction (7 more than in July 2012) with a total capacity of 63 GW. The average construction time of the units under construction, as of the end of 2012, is 8 years. However:

- Nine reactors have been listed as "under construction" for more than 20 years and four additional reactors have been listed for 10 years or more.
- Forty-five projects do not have an official planned start-up date on the International Atomic Energy Agency's (IAEA) database.
- At least 23 have encountered construction delays, most of them multi-year. For the remaining 43 reactor units, either construction began within the past five years or they have not yet reached projected start-up dates, making it difficult or impossible to assess whether they are on schedule or not.
- Two-thirds (44) of the units under construction are located in three countries: China, India and Russia.

The average construction time of the 34 units that started up in the world between 2003 and July 2013 was 9.4 years.

Reactor Status and Nuclear Programs

- **Startups and Shutdowns.** Only three reactors started up in 2012, while six were shut down[10] and in 2013 up to 1 July, only one started up, while four shutdown decisions—all in the U.S.—were taken in the first half of 2013.[11] Three of those four units faced costly repairs, but one, Kewaunee, Wisconsin, was running well and had received a license renewal just two years ago to operate up to a total of 60 years; it simply became uneconomic to run. As of 1 July 2013, there were only two reactors operating in Japan and how many others will receive permission to restart and over what timeframe remains highly uncertain.
- **Newcomer Program Delays.** Engagement in nuclear programs has been delayed by most of the potential newcomer countries, including Bangladesh, Belarus, Jordan, Lithuania, Poland, Saudi Arabia and Vietnam.

[9] According to BP, "Statistical Review of World Energy", June 2013.

[10] Shutdown is defined as definitively taken off the grid. The shutdown date is the last day when the reactor generated electricity.

[11] The operator decided in June 2013 to shut down the two San Onofre units in California. However, they have not generated electricity for over a year. So in the WNISR database the units have been withdrawn for the year 2012 rather than 2013.

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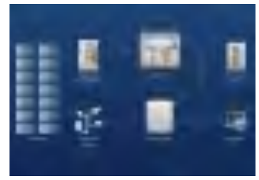


A Solar System Is Installed in the US Every 4 Minutes

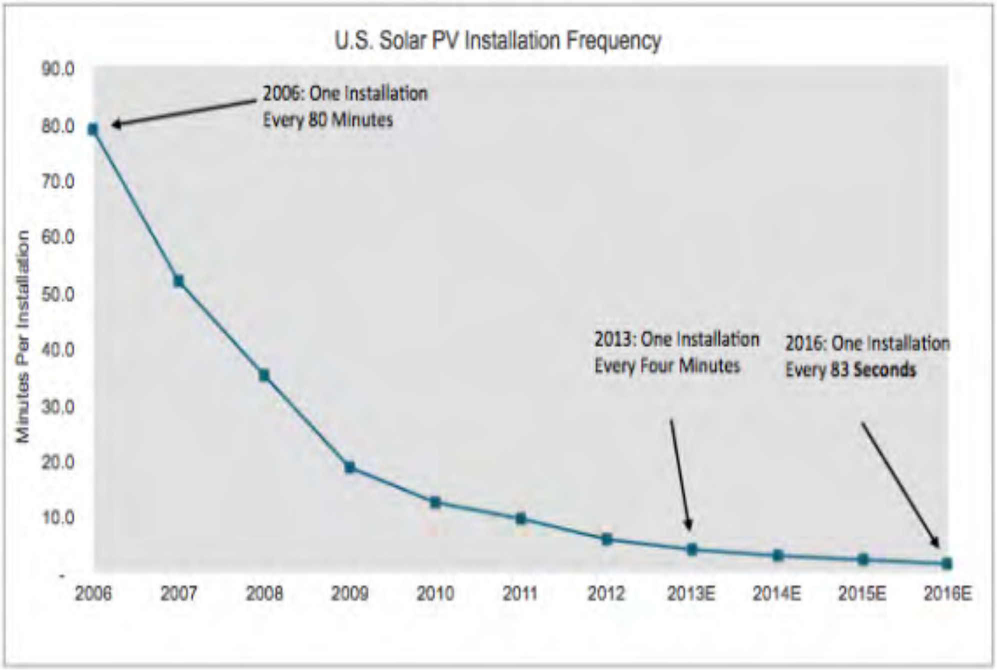
The industry will soon install one solar system every minute and a half.

Stephen Lacey
August 19, 2013

A lot happens in America every four minutes. During that short time period, 30 babies are born, 4,080 McDonald's Big Macs are consumed, and 48,000 tons of CO2 are emitted.

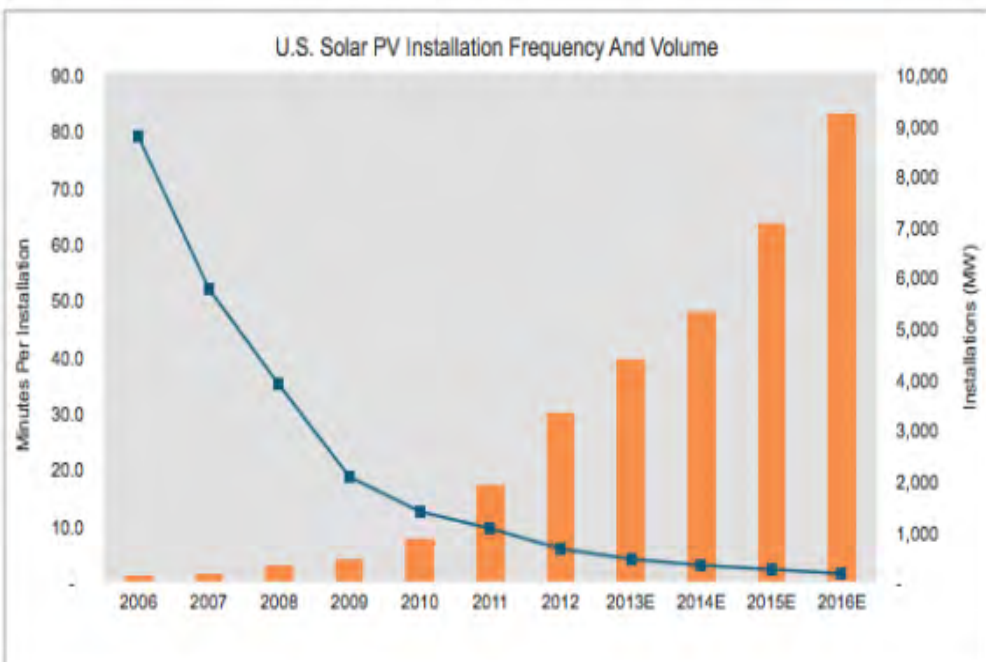
And as it turns out, the U.S. is now installing one solar photovoltaic (PV) system every four minutes as well. If market growth continues at its current pace, the American solar industry could be installing a system every minute and twenty seconds by 2016.

That's a dramatic difference from 2006, when installers were only putting up one system every 80 minutes. Shayle Kann, vice president of GTM Research, documents the accelerating speed of solar deployment in the chart below:



Source: Shayle Kann, GTM Research

Here's another way to look at those numbers. This chart pairs the frequency of solar deployment along with projected capacity:



Source: Shayle Kann, GTM Research

It may not quite match Big Mac sales yet, but solar is on an extraordinarily fast growth trajectory. According to figures from GTM Research, two-thirds of all distributed solar in the U.S. has been installed over the last 2 1/2 years. And by 2016, cumulative installations of distributed PV will double.

That means the U.S. will hit 1 million cumulative residential solar installations by then -- making the market in 2016 ten times larger than it was in 2010.

For more information on American solar trends, check out the U.S. Solar Market Insight Report *from GTM Research and SEIA.*

TAGS: gtm research, solar installations, solar market insight, solar markets

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Chart: 2/3rds of Global Solar PV Has Been Installed in the Last 2.5 Years

Recurrent Energy

And capacity will nearly double in the next 2.5 years.

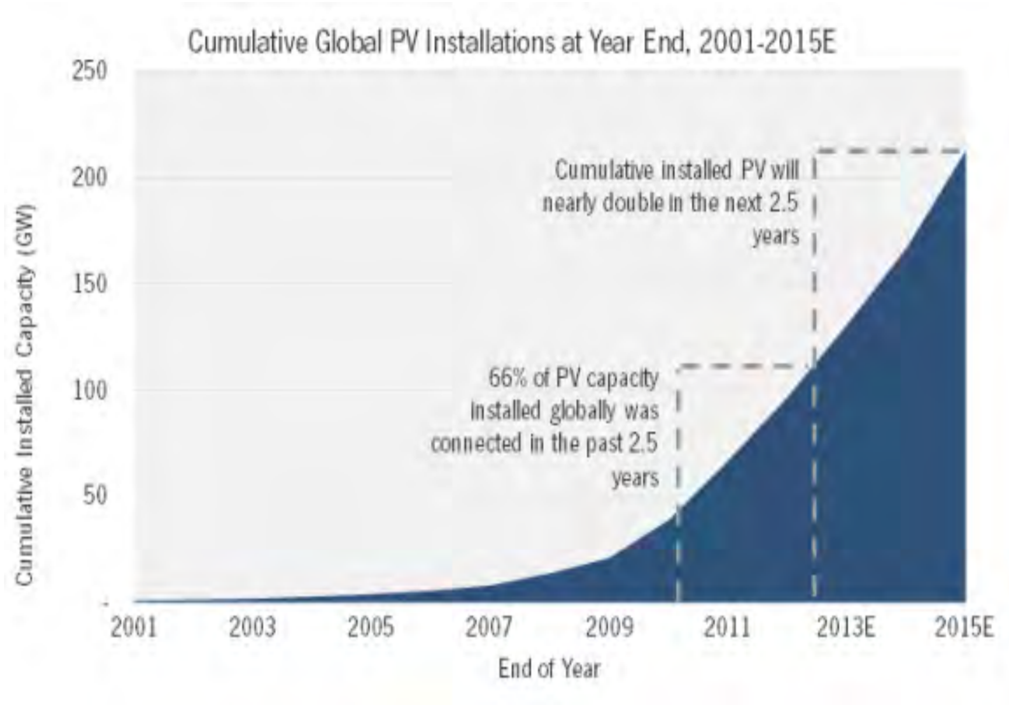
Stephen Lacey
August 13, 2013

If you want to understand why people so often compare deployment trends in solar photovoltaics (PV) to Moore's law in computing, consider this statistic: two-thirds of all solar PV capacity in place worldwide has been installed since January 2011.

Let's put that into perspective. It took nearly four decades to install 50 gigawatts of PV capacity worldwide. But in the last 2 1/2 years, the industry jumped from 50 gigawatts of PV capacity to just over 100 gigawatts. At the same time, global module prices have fallen 62 percent since January 2011.

Even more amazingly, the solar industry is on track to install another 100 gigawatts worldwide by 2015 -- nearly doubling solar capacity in the next 2 1/2 years.

Those statistics and the chart below, courtesy of GTM Research Senior Analyst MJ Shiao, illustrate the exponential growth in the global PV market.



Source: GTM Research

And as Shiao's second chart below shows, the U.S. distributed solar market is on pretty much the same growth trajectory. More than two-thirds of America's distributed PV (everything except for utility-scale projects) has been installed since January 2011. And by 2015, the country's distributed PV market is expected to jump by more than 200 percent.

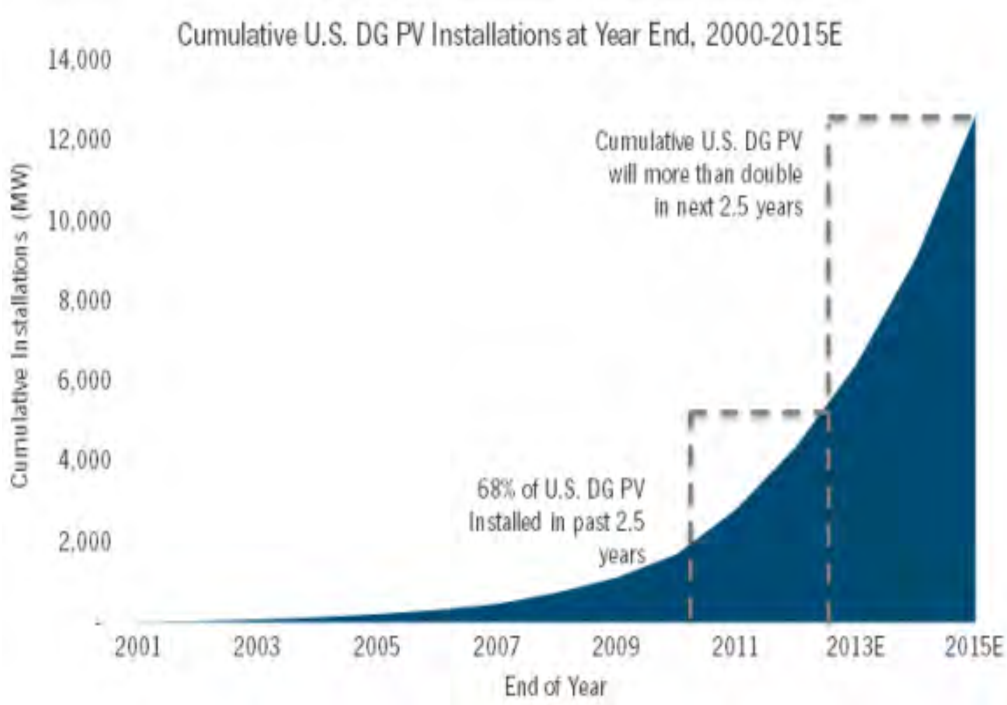


Chart: GTM Research/SEIA U.S. Solar Market Insight

There are a few key takeaways from these figures.

First, utilities still dismissing solar as inconsequential or "cute" may soon be in for a rude awakening. According to the *Solar Market Insight* report from GTM Research and SEIA, the national average for residential system prices fell another 18 percent last year; non-residential prices fell 13.3 percent.

The falling cost and price of installation is starting to open up new markets without incentives. As Shayle Kann, vice president of GTM Research, pointed out recently, roughly 3,000 residential solar systems were installed in California without the use of any state incentives in the first quarter of this year.

"This is emblematic of a sea change in the solar industry, and even more importantly, in the energy industry," wrote Kann.

But this rapid increase in installations won't create challenges for just utilities -- it will also create challenges for the solar industry itself. Since the solar market is still at the beginning of a steep growth curve, it's hard to say whether the business models and technologies we know today are going to be successful in the future.

This will likely mean more bankruptcies and more consolidation. It will also test the reliability of products operating in the field.

Because two-thirds of PV capacity in the field today was only installed in the last couple of years, a majority of the products are still very new. Solar is a multi-decade investment, and there is uncertainty around how new hardware will perform over the long term, explained Shiao.

"We're really at the beginning stages of understanding PV in terms of products in the field, viable business models, and effects on the grid, especially when you consider that PV is being sold many times as a twenty-year asset. Now is the time to look deeper into issues surrounding product reliability, market sustainability and O&M business models."

The boom in distributed solar is underway. And we've only just begun to understand the implications.

For more on product performance, check out the PV module reliability scorecard from GTM Research and PV Evolution Labs. And for more on U.S. solar trends, read the U.S. Solar Market Insight *report.*

TAGS: distributed solar, gtm research, reliability, solar industry, solar installations, utilities

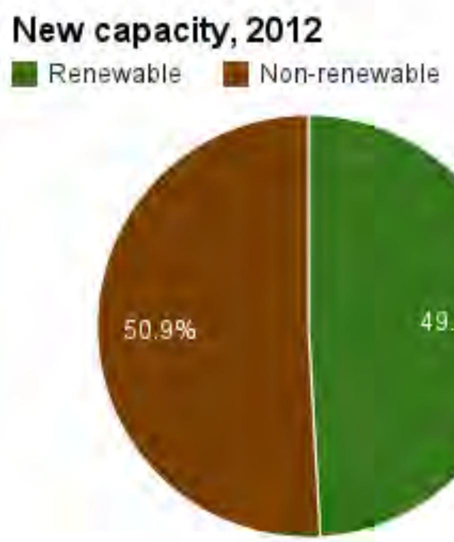
18 Jan 2013 2:47 PM

Nearly half of new U.S. power capacity in 2012 was renewable — mostly wind

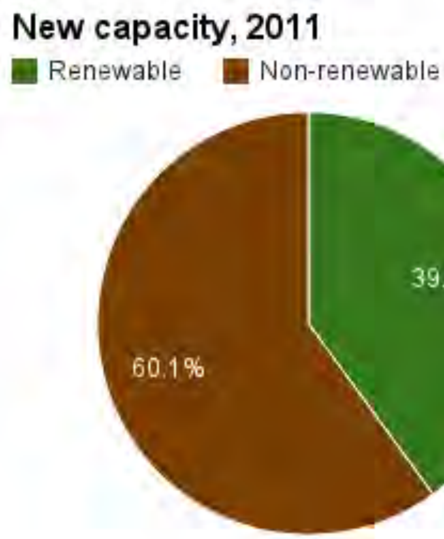
By Philip Bump

As predicted, almost half of the new power-generating capacity installed in the United States last year was renewable.

The Federal Energy Regulatory Commission recently released its December update on the nation's energy infrastructure [PDF]. When we last checked on the data, it suggested that some 46 percent of new capacity — January through October — was renewable. Well, that ratio improved over the last two months of the year. Ultimately, 49.1 percent of new capacity was renewable.



Compare that to 2011, when less than 40 percent was renewable.

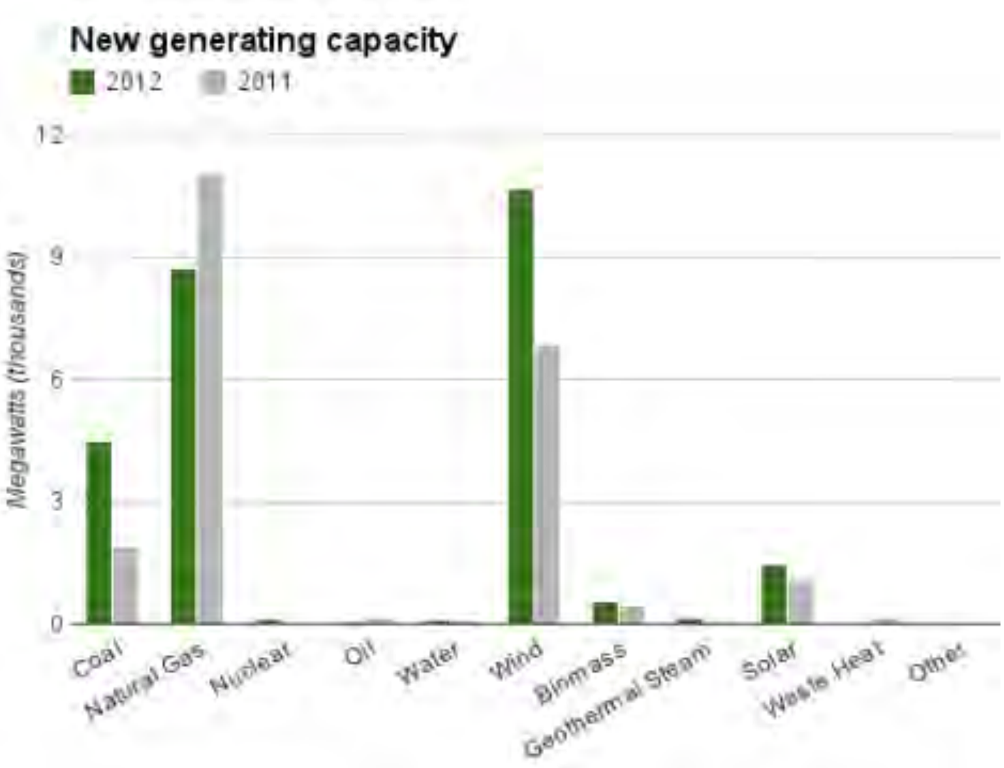


GreenBiz.com explains that end-of-year boost.

> The latest Energy Infrastructure Update report from the Office of Energy Projects, part of the Federal Energy Regulatory Commission (FERC), lists just shy of 13GW of green energy projects coming online last year, a more than 50 percent rise on the 8.5GW of capacity added in 2011.
>
> Around a quarter of this capacity became operational in December alone, as wind energy developers rushed to complete projects before the feared expiration of federal tax credits.

We noted last September the furious rush to bring those projects to completion. Seems like it worked.

The FERC report breaks out the new capacity by type.



Wind ended up being the biggest new source of capacity, beating even natural gas (which itself had a pretty good year).

The question is: Can this pace be sustained into 2013? The tax credit was extended as part of the fiscal cliff deal, but only temporarily. Our David Roberts thinks 2013 will be another big year for the industry. It will certainly be better than it would have been without the extension — but we'll have to wait 12 months to see if Roberts is right.

Philip Bump wrote about the news for Gristmill. He now writes for The Atlantic Wire.

Office of Energy Projects
Energy Infrastructure Update
For September 2013

Electric Generation Highlights

- Basin Electric Power Cooperative's 45 MW natural gas-fired Pioneer Generating Station Phase 1 in Williams County, ND is online. Phase 2, with 90 MW, is expected to come online in January 2014.
- GreenWhey Energy's 3.2 MW biomass fueled project in Polk County, WI is online. GreenWhey's two anaerobic digesters convert wastewater from the area cheese processing plants into electricity which is sold under long-term contract to Xcel Energy.
- Three solar plants with a total of 5.6 MW capacity in NC are online: 1) 2 MW Central Farm 2 in Robeson County; 2) 1.6 MW Innovative Solar 1 & 2 in Buncombe County; and 3) FLS Energy Inc.'s 2 MW Taylor Solar Farm in Robeson County. The power generated from these facilities is sold to Progress Energy Carolinas under long-term contracts.

New Generation In-Service (New Build and Expansion)

	September 2013		January – September 2013 Cumulative		January – September 2012 Cumulative	
Primary Fuel Type	No. of Units	Installed Capacity (MW)	No. of Units	Installed Capacity (MW)	No. of Units	Installed Capacity (MW)
Coal	0	0	2	1,543	3	2,359
Natural Gas	1	45	51	5,854	91	5,079
Nuclear	0	0	0	0	1	0
Oil	0	0	7	27	38	73
Water	0	0	11	116	10	8
Wind	1	2	9	961	87	5,043
Biomass	3	5	57	192	102	413
Geothermal Steam	0	0	1	14	9	148
Solar	5	7	146	1,935	228	1,091
Waste Heat	0	0	2	76	1	3
Other	2	0	3	0	4	0
Total	12	58	289	10,717	574	14,217

Source: Data derived from Ventyx Global LLC, Velocity Suite.

Total Installed Operating Generating Capacity

	Installed Capacity (GW)	% of Total Capacity
Coal	336.38	28.94%
Natural Gas	487.96	41.98%
Nuclear	106.78	9.19%
Oil	47.15	4.06%
Water	96.66	8.32%
Wind	60.15	5.18%
Biomass	15.20	1.31%
Geothermal Steam	3.78	0.33%
Solar	6.27	0.54%
Waste Heat	1.14	0.10%
Other	0.80	0.07%
Total	1,162.27	100.00%

Source: Data derived from Ventyx Global LLC, Velocity Suite.

Paving the path for next-generation nuclear energy

May 6, 2013 - 2:26pm

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Renewed energy and enhanced coordination are on the horizon for an international collaborative that is advancing new, safer nuclear energy systems.

Deputy Assistant Secretary Kelly

Deputy Assistant Secretary for Nuclear Reactor Technologies

Nuclear power reactors currently under construction worldwide boast modern safety and operational enhancements that were designed by the global nuclear energy industry and enhanced through research and development (R&D) by the U.S. Department of Energy and its international counterparts. Today, experts around the world are collaborating to further advance nuclear technology to meet future energy needs.

Developing the next generation of nuclear reactor technology is an ambitious goal, even for countries with large-scale nuclear energy research programs. That's why the U.S. has been working with international partners to coordinate efforts, resources and schedules to achieve success.

The **Generation IV International Forum (GIF)** was established to address key technical issues associated with designing, building and operating next-generation nuclear energy systems. The Generation-IV designs will use fuel more efficiently, reduce waste production, be economically competitive and meet stringent standards of safety and proliferation resistance.

Some of these revolutionary designs could be demonstrated within the next decade, with commercial deployment beginning in the 2030s.

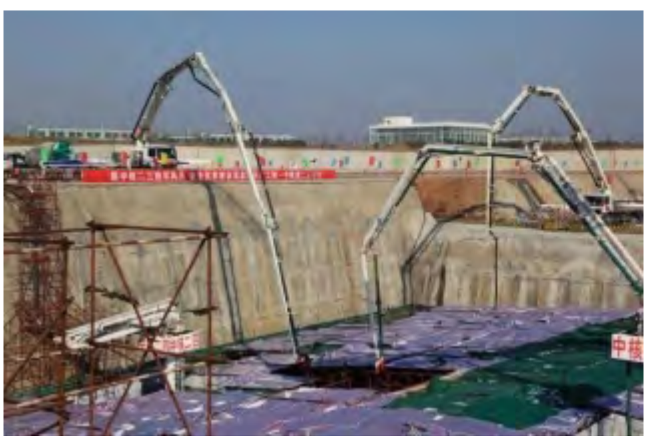
GIF includes 12 member countries and the European Atomic Energy Community (Euratom), evolving from nine original member countries who signed the GIF charter in July 2001. These nine members, Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, the United Kingdom and the United States, were later joined by Switzerland, Euratom, the People's Republic of China and the Russian Federation to form the current 13 member forum.

For more than a decade, GIF has led international collaborative efforts to develop next-generation nuclear energy systems that can help meet the world's future energy needs. The advanced systems are designed to meet four overarching goals: sustainability, safety and reliability, economic competitiveness, and proliferation resistance/physical protection. More specifically, our goals for these Generation IV reactor systems are to:

- provide sustainable energy generation that meets clean energy objectives, promotes long-term availability of systems and utilizes fuel more effectively
- minimize nuclear waste and reduce long term stewardship burden
- excel in safety and reliability
- have a very low likelihood and degree of reactor core damage in the case of an accident
- greatly reduce the need for offsite emergency response
- have a life cycle cost advantage over other energy sources
- have a level of financial risk comparable to other energy projects
- be a very unattractive route for diversion or theft of weapon-usable materials, and
- provide increased physical protection against acts of terrorism

With these goals in mind, some 100 experts evaluated 130 reactor concepts before GIF selected **six reactor technologies** for further research and development. Five of the designs recycle fissionable material and produce less nuclear waste. Four designs co-generate heat that could be used for industrial processes such as seawater desalination or plastics production.

Today, China has begun construction of a prototype Generation-IV reactor, and both France and Russia are developing advanced sodium fast reactor designs for near-team demonstration. Prototype lead fast reactors are expected to be built in Russia and Europe in the 2020 timeframe.



HTR-PM First Concrete Deployment on December 9, 2012
Photo Courtesy of Dr. ZHANG, Zuoyi, Director/Professor, Institute of Nuclear and New Energy Technology (INET), Tsinghua University, Beijing, China

As the current GIF chair, I believe the organization is poised for a period of enhanced collaboration, communication, and student involvement. During a meeting next week in Beijing, China, I expect the GIF governing body to approve a new strategic plan — the first in a decade — and begin its implementation.

The plan outlines how GIF will enhance R&D collaboration and optimize coordination with other international research and regulatory entities among GIF members. The plan also includes an updated technology roadmap, which assesses the status and future plans of each next-generation nuclear system under development by GIF members.

Watch for updates from next week's meeting and learn more about GIF at the Generation IV International Forum **website**.

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Suzanne Goldenberg, US environment correspondent
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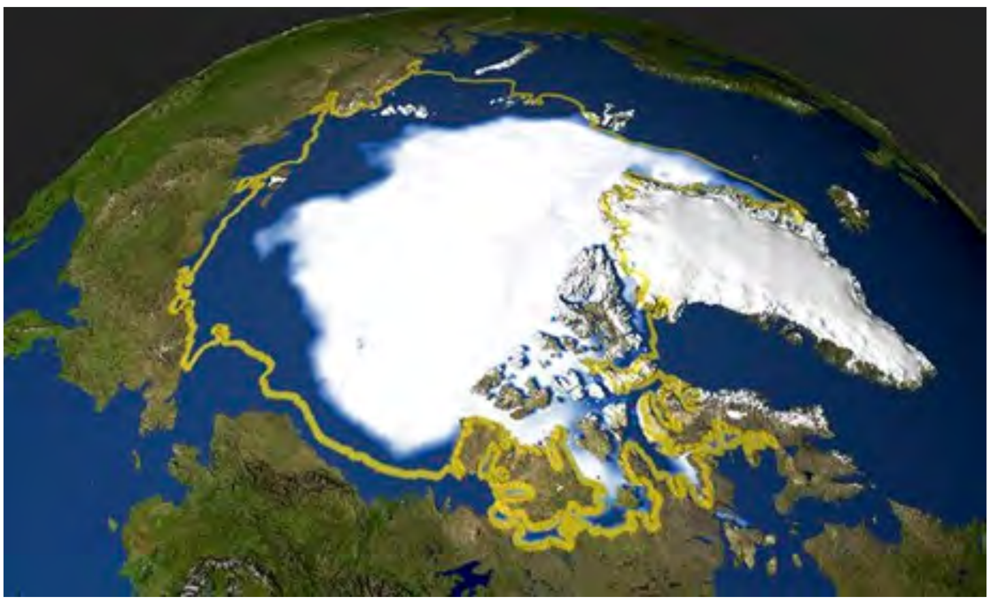

A Nasa image of declining Arctic sea ice in 2005 (compared with 1979 shown by the yellow line). Photograph: Ho/AFP/Getty Images

Al Gore said on Wednesday it would be "insane, utterly mad and delusional in the extreme" to turn to geo-engineering projects to avoid a climate catastrophe.

The UN climate panel, in the next edition of its blockbuster reports, will warn that governments might have to extract vast amounts of greenhouses gases from the air by 2100 to limit climate change, according to a draft copy of the report seen by Reuters.

But the former vice president of the US said that searches for an instant solution, which he said were born of desperation, were misguided and could lead to an even bigger catastrophe.

"The idea that we can put a different form of pollution into the atmosphere to cancel out the effects of global warming pollution is utterly insane," he told a conference call for South African reporters.

He added: "The fact that some scientists who should know better are actually engaged in serious discussion of those alternatives is a mark of how desperate some of them are feeling due to the paralysis in the global political system."

In March Gore will expand his climate leadership training programmes to South Africa. He said he believed those leadership training sessions (this is his 24th) had developed a cadre of leaders who were helping to find political solutions for climate change.

The draft climate report of the Intergovernmental Panel on Climate Change, due for release in Germany in April, said governments might have to turn increasingly to technologies for "carbon dioxide removal" to keep warming below the dangerous threshold of 2 degrees.

The draft said those technologies might involve capturing and burying emissions from coal-fired power plants, or planting more forests. But there has been debate in the environmental community over other more radical solutions.

On geo-engineering Gore drew a distinction between small-scale interventions, such as white roofs, and large-scale projects meant to extract or neutralise emissions from the air or block the sunlight. Those ideas, he said, carried enormous risks.

"The most discussed so-called geo-engineering proposals – like putting sulphur dioxide in the atmosphere to reflect incoming sunlight – that's just insane. Let's just describe that clearly – it is utterly mad," Gore told the conference call.

He warned that such large and untested experiments carried enormous risks while "doing nothing to address other consequences of climate change such as ocean acidification".

He said: "We are already engaged in a planet-wide experiment with consequences we can already tell are unpleasant for the future of humanity. So the hubris involved in thinking we can come up with a second planet-wide experiment that would exactly counteract the first experiment is delusional in the extreme."

Gore was also cool on the other quick-fix of nuclear power, advocated by some. Late last year four leading US scientists, including the climatologist James Hansen, wrote an open letter urging environmentalists to rethink their opposition to nuclear power.

Gore's re-thinking has apparently gone in the other direction. He told the call he had been an enthusiastic supporter of nuclear energy when he was in Congress. He was not opposed to nuclear energy now, he said. But he said the current state of technology in the nuclear energy industry did not yet warrant a big expansion.

"I do believe that it may be possible for scientists and researchers to develop a better and more inherently safer and cheaper form of nuclear reactor, which may yet play a significant role in resolving this crisis," he told the call. But he added: "It is not available now."

He said he thought such nuclear developments were still 10 or 15 years away. "Unless there are breakthroughs I think the role of nuclear power is likely to be limited to near the level of contribution it is now," he said.

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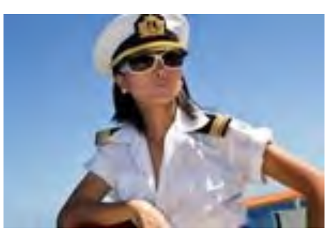

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Print this post

Hyundai to offer Tucson Fuel Cell vehicle to LA-area retail customers in spring 2014; Honda, Toyota show latest FCV concepts targeting 2015 launch

21 November 2013

Hyundai Tucson Fuel Cell. Click to enlarge.

At the Los Angeles Auto Show, Hyundai announced plans to offer its next-generation Tucson Fuel Cell vehicle for the US market for $499 per month, including unlimited free hydrogen refueling and At Your Service Valet Maintenance at no extra cost. Availability begins in Spring 2014 at several Southern California Hyundai dealers.

Also at the LA Auto Show, the new Honda FCEV Concept made its world debut. The concept expresses a potential styling direction for Honda's next-generation fuel-cell vehicle anticipated to launch in the US and Japan in 2015, followed by Europe. At the Tokyo Motor Show, Toyota highlighted its own new FCV Concept with a world premiere.

HYUNDAI TUCSON FUEL CELL

Hyundai will initially offer the Tucson Fuel Cell to customers in the Los Angeles/Orange County region for $499 per month for a 36-month term, with $2,999 down. This includes unlimited free hydrogen refueling.

> When we spoke to customers interesting in driving a hydrogen fuel cell vehicle, many wondered what the cost of hydrogen would be. To ease those concerns as we build-out the hydrogen refueling network, we thought covering this cost for these early adopters in the monthly payment was the best approach, and consistent with other aspects of our Hyundai Assurance program. It's our way of saying: 'This is another thing you don't have to worry about, we've got your back.
>
> —John Krafcik, president and CEO, Hyundai Motor America

In addition, Tucson Fuel Cell owners will enjoy all the same services of the Hyundai Equus "At Your Service" valet program. As Equus owners have enjoyed since its introduction in 2010, should a Tucson Fuel Cell require any service, a Hyundai dealer will pick up the vehicle and provide a loaner, then return their car after service to their home or business, at no charge.

Customers interested in the Tucson Fuel Cell can indicate their interest (the first step in the ordering process) beginning by visiting Hyundai.com.

The first four Hyundai dealers to offer the Tucson Fuel Cell to Southern California customers are Hardin Hyundai in Anaheim; Win Hyundai in Carson; Keyes Hyundai in Van Nuys; and Tustin Hyundai, with additional Hyundai dealers to follow. Availability of the Tucson Fuel Cell will expand to other regions of the country consistent with the accelerating deployment of hydrogen refueling stations.

To achieve societal goals of significant reduction in greenhouse gas emissions, more and more consumers will need to drive zero-emissions vehicles. Currently, there's an ongoing debate about the future of the electric vehicle, which Hyundai condensed into two approaches:

1. Store more electricity on-board using more/larger batteries
2. Create electricity on-board with hydrogen-powered fuel cell technology

Hyundai is taking the second approach. While the battery electric vehicle has made progress in recent years, with improved affordability and energy storage capability, for most consumers, range anxiety and lengthy recharging time remain formidable obstacles, Hyundai said. In addition, affordable electric vehicle technology is best suited to smaller urban vehicles, not larger family and utility vehicles that many families require to meet all of their needs. Because of the inherent weight and cost of batteries, and the chemistry and physics that drive slow recharge times, today's electric vehicles have practical limits for many consumers, Hyundai suggested.

> Hydrogen-powered fuel cell electric vehicles represent the next generation of zero-emission vehicle technology, so we're thrilled to be a leader in offering the mass-produced, federally certified Tucson Fuel Cell to retail customers. The superior range and fast-fill refueling speed of our Tucson Fuel Cell vehicle contrast with the lower range and slow-charge characteristics of competing battery electric vehicles. We think fuel cell technology will increase the adoption rate of zero-emission vehicles, and we'll all share the environmental benefits.
>
> —John Krafcik

The Tucson Fuel Cell offers:

- Driving range up to an estimated 300 miles;
- Capable of full refueling in less than 10 minutes, similar to gasoline;
- Minimal reduction in daily utility compared with its gasoline counterpart;
- Instantaneous electric motor torque (221 lb-ft);
- Minimal cold-weather effects compared with battery electric vehicles;
- Reliability and long-term durability;
- No moving parts within the power-generating fuel cell stack;
- More than two million durability test miles on Hyundai's fuel cell fleet since 2000; and
- Extensive crash, fire and leak testing successfully completed.

Hyundai began production of the ix35 Fuel Cell (the Tucson's counterpart in Europe) at the company's Ulsan manufacturing plant in Korea in January 2013; the first complete car rolled off the assembly line on 26 February 2013.

The ix35 Fuel Cell—Hyundai's third-generation fuel cell vehicle—delivers large improvements over its predecessor, including a driving range that has been extended by more than 50% and fuel efficiency gains of more than 15%.

The ix35 Fuel Cell is equipped with a 100 kW electric motor, allowing it to reach a maximum speed of 160 km/h (99 mph). Two hydrogen storage tanks, with a total capacity of 5.64 kg, enable the vehicle to travel a total of 594 km (369 miles) on a single charge, and it can reliably start in temperatures as low as -20 degrees Celsius. The energy is stored in a 24 kWh lithium-ion polymer battery, jointly developed with LG Chemical.

The Tucson Fuel Cell begins mass production for the US market in February 2014 at Ulsan—the plant that also manufactures the Tucson gasoline-powered CUV. Manufacturing the Tucson Fuel Cell at the same plant allows Hyundai to leverage both the high quality and cost-efficiency of its popular gasoline-powered Tucson platform.

Click to enlarge.

According to 2013 studies on well-to-wheel greenhouse-gas emissions (GHG) by the Advanced Power and Energy Program at the University of California, Irvine, hydrogen-powered fuel cell vehicles have the lowest overall emission levels of all alternative fuel entries. Well-to-wheel emissions for hydrogen vehicles sourced from natural gas are lower than battery electric vehicles (based on the average carbon footprint of the entire US grid), and less than half of equivalent gasoline vehicle emissions. Hydrogen emissions sourced from biogas are a tiny fraction of equivalent gasoline vehicle emissions.

(Hyundai's Fuel Cell prototypes have relied on hydrogen generated at the Orange County Sanitation District near its Fountain Valley headquarters, where methane from sewage is turned into hydrogen.)

Hyundai is also partnering with Enterprise Rent-A-Car to make the Tucson Fuel Cell available to consumers at select locations in the Los Angeles/Orange County region. This partnership will enable interested consumers to evaluate the Tucson Fuel Cell for their lifestyles on a multi-day basis, with rental availability also planned for Spring 2014.

HONDA FCEV CONCEPT

Significant technological advancements to the fuel-cell stack have yielded more than 100 kW of power output. The power density is now 3 kW/L, an increase of 60%, with the stack size reduced 33% compared to the FCX Clarity. The next-generation Honda FCEV is anticipated to deliver a driving range of more than 300 miles (483 km) with a quick refueling time of about three minutes at a pressure of 70 MPa.

The Honda FCEV Concept features sweeping character lines underscored by an ultra-aerodynamic body. The Honda FCEV Concept also delivers ample passenger space and seating for 5-passengers thanks to new powertrain packaging efficiencies.

The Honda FCEV Concept. Click to enlarge.

The next generation fuel cell-electric vehicle launching in 2015 will feature the first application of a fuel-cell powertrain packaged completely in the engine room of the vehicle, allowing for efficiencies in cabin space as well as flexibility in the potential application of FC technology to multiple vehicle types in the future.

> You probably know the conventional wisdom on fuel cells—that they are the technology of the future and always will be. We're working to change that mindset. Too often talk about future timelines in 2015 and 2020 is met with skepticism, either about the technology or the commitment. So let me give you a word of advice today—don't confuse our candor with a lack of progress. The advancement we are making is substantial, meaningful and very real.
>
> We also acknowledge that the hydrogen refueling infrastructure needs to expand dramatically both here in California and across this nation. That's why we were pleased when Governor Jerry Brown signed into law a provision to kick-start an expanded network for refueling. This also is why Honda is an enthusiastic participant in a federal program, H_2USA.
>
> In the meantime, the mass production fuel cell electric vehicle under development in our engineering labs will be our next significant step forward in this process. So, what you see here on stage is more than a concept car—this Honda FCEV Concept is a commitment to the future of mobility.
>
> —Mike Accavitti, senior vice president of American Honda Motor Co.

Honda has invested nearly two decades in the development and deployment of fuel-cell technology through extensive real world testing, including the first government fleet deployment and retail customer leasing program. Honda has made significant technological advancements in fuel-cell operation in both hot and sub-freezing weather, meeting stringent emissions requirements and safety regulations since the introduction of its first generation fuel-cell vehicle, the FCX in 2002.

Honda began leasing its first-generation FCEV, the Honda FCX, in 2002 and has deployed vehicles in the US and Japan, including its successor, the FCX Clarity, which was named the 2009 World Green Car. Honda has delivered these vehicles to individual retail consumers in the US and collected valuable data concerning real-world use of fuel cell-electric vehicles and hydrogen stations.

Honda's current fuel cell-electric vehicle, the FCX Clarity, launched in July 2008. (Earlier post.) With the V-flow fuel cell stack positioned down the center of the vehicle and the electric motor located in the front of the vehicle, Honda was able to maintain the Clarity's futuristic styling while delivering 240 miles (386 km) of driving range.

In the effort to speed the advance of a refueling infrastructure, in May 2013, American Honda joined the public-private partnership H_2USA, which brings together automakers, government agencies, hydrogen suppliers, and the hydrogen and fuel-cell industries to coordinate research and identify cost-effective solutions to deploy infrastructure that can deliver affordable, clean hydrogen fuel in the United States.

In July 2013, Honda entered into a long-term collaborative agreement with General Motors to co-develop the next-generation of fuel-cell systems and hydrogen storage technologies, aiming for the 2020 timeframe. The collaboration expects to succeed by sharing technological expertise, economies of scale and common sourcing strategies. (Earlier post.)

TOYOTA FCV CONCEPT

The Toyota FCV Concept is a practical concept of the fuel cell vehicle Toyota plans to launch around 2015 as a pioneer in the development of hydrogen-powered vehicles. The vehicle has a driving range of at least 500 km (311 miles) and refueling times as low as three minutes.

Toyota FCV Concept Click to enlarge.

With Toyota's proprietary small, light-weight FC Stack and two 70 MPa high-pressure hydrogen tanks placed beneath the specially designed body, the Toyota FCV Concept can accommodate up to four occupants.

The Toyota FC Stack has a power output density of 3 kW/L, more than twice that of the current "Toyota FCHV-adv" FC Stack, and an output of at least 100 kW. In addition, the FC system is equipped with Toyota's high-efficiency boost converter. Increasing the voltage has made it possible to reduce the size of the motor and the number of fuel cells, leading to a smaller system offering enhanced performance at reduced cost.

Fully fueled, the vehicle can provide enough electricity to meet the daily needs of an average Japanese home (10 kWh) for more than one week.

November 21, 2013 in Fuel Cells, Hydrogen | Permalink | Comments (36) | TrackBack (0)

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Comments

gorr!!
Looks like you have a car to look forward to!

Posted by: Davemart | November 21, 2013 at 02:40 AM

A welcomed hand to Hyundai to be the first major manufacturer to break a taboo with 369 miles FCEVs at $499/month including free fuel. That may cost less than equivalent ICEVs, specially for people with above average driving needs.

Anti FCEVs posters will have a fit?

To install selected (free) hydrogen stations is an extremely smart (à la Tesla) commercial move to promote early usage of FCEVs. Let's hope that Toyota and Honda will offer the same level of service for their FCEVs a few months latter.

Will the other 17 majors follow? If so, when will they have equivalent FCEVs and services?

Posted by: HarveyD | November 21, 2013 at 08:32 AM

Of the 3 vehicles, it's the toyota that i like the best, it should do more mpg then the tucson but with free fuel i might be interrested in the tucson in 2025 approx.

Posted by: Gorr | November 21, 2013 at 09:01 AM

The (well-to-wheel) GHG emissions graft is very interesting.

However, the high GHG emissions for BEVs is only true where the power grid mix includes a large quantity of coal fired and NG power plants. Where Hydro + Wind + Solar + Nuclear are used, BEVs GHG emissions would be as low as FCEVs using biogas from waste water.

Current and near future gasoline/diesel and NG ICE vehicles emit way too much GHGs and should be phased out as soon as possible.

Concurrently, all coal fired power stations should be phased out in favor of Wind, Solar and Hydrogen making/storage facilities.

Posted by: HarveyD | November 21, 2013 at 09:17 AM

Yep, the graph is dishonest.

For an accurate comparison there would need to be a bar for the FCEV running grid electricity produced H2 like the EV on grid power graph.

And a bar for the EV running solar/wind electricity, comparable to their FCEV running on waste water methane.

Posted by: Bob Wallace | November 21, 2013 at 10:27 AM

It's not so much that the graph is dishonest, it's rather error of omission. They forgot to include the CO2 of BEV charged from zero-CO2-electricity, perhaps because the result would be an obvious zero to everyone, hence no need to include it in.

I. Introduction

Fuel Cells for Corporate Sustainability

U.S. companies are finding that going green helps earn more green; more reliable and efficient sources of power help boost productivity as well as profits. As businesses turn to cleaner and more efficient technologies to help reduce their greenhouse gas emissions, many are turning to fuel cells to supplement their energy portfolios, including large, multi-megawatt (MW) orders in both ongoing and new end user markets.

Several recent studies reinforce the idea that sustainability can be good for the bottom line. A 2012 survey by research firm Verdantix indicates that many CFOs see sustainability as a key driver of financial performance, a similar result found in a 2011 MIT study, *Sustainability & Innovation Global Executive Study and Research Project.*[1]

Fuel cells are reliable, efficient, quiet, and significantly cut carbon emissions. In the age of distributed generation (power generated onsite), fuel cells also offer facilities a clean break from an electric grid plagued by violent weather disruptions and growing issues with cyber security. In addition, fuel cells are compatible with other energy technologies – whether renewable such as solar, wind or biogas, or traditional, such as natural gas or batteries. Fuel cells complement and improve energy technology performance and, in turn, help companies meet their sustainability goals while boosting their bottom line.

2012 Fuel Cell Customers

Repeat customers in blue

Adobe Systems	+ 0.4 MW
Americold	+ 0.6 MW
Apple	+ 5 MW
AT&T	+ 9.6 MW
CBS Studios	+ 4.8 MW
Coca-Cola	+0.5 MW; +56 forklifts
eBay	+ 6 MW
JMB Realty	+ 0.4 MW
Lowe's	+ 161 forklifts
Mercedes-Benz	+72 forklifts
News Corp.	+ 0.4 MW
Owens Corning	+ 0.4 MW
Procter & Gamble	+ 340 forklifts
Roger's Gardens	+ 0.015 MW
San Jose Sharks	+ 0.4 MW
Sysco	+ 524 forklifts
Walmart	+ 3.6 MW

+ 32.1 MW
+ 1,131 forklifts

A few of this year's big name fuel cell customers include Fortune 500 companies Apple, eBay, Coca-Cola, and Walmart, all of which trust fuel cells to provide reliable power to data centers, stores, and facilities. Some are purchasing huge, multi-megawatt (MW) systems, including three of the largest non-utility purchases of stationary fuel cells in the world by AT&T, Apple and eBay – 17 MW, 4.8 MW and 6 MW respectively. Others are replacing fleets of battery forklifts with fuel cells. Sysco, the food distributor, has more than 700 fuel cell-powered forklifts operating at seven facilities, with more on order. Walmart now has more than 500 fuel cell forklifts operating in three warehouses, including a freezer facility.

In our 2010 and 2011 Business Case reports, Fuel Cells 2000 profiled a total of 62 companies using fuel cells. The 2011 report also included second looks at 10 repeat customers from the previous report. This new 2012 report narrows the focus to a handful of companies either incorporating fuel cells with other technologies in order to better achieve their sustainability goals, and/or becoming repeat customers and installing large-scale systems at their facilities. The companies profiled are collectively saving millions of dollars in electricity costs while reducing carbon dioxide emissions by hundreds of thousands of metric tons per year.

II. New Markets, New Customers

The fuel cell industry is attracting customers from all areas of commerce – computing/software, television/media, real estate development, food/beverage processing, grocery stores, hotels, warehouse/distribution and much more. Many companies in these sectors are turning into repeat customers, coming back to purchase additional systems for their facilities.

Data Centers

Fuel cells are extremely reliable and generate high quality power, making them a valuable technology for data centers, hospitals, or other facilities where power outages are not an option. Banks, call centers, and prisons share this critical power need as well.

Two of the biggest names in computing, Apple and Microsoft, are each making a major investment in fuel cells for their respective data centers. Apple is in the process of installing a 4.8 MW Bloom Energy fuel cell system alongside 20 MW of solar panels at its new data center in Maiden, North Carolina. This historic installation is explained in greater detail in the following pages.

Microsoft recently announced a first-of-its-kind fuel cell installation at its Cheyenne, Wyoming, data facility that will come online in spring 2013. The 300-kW FuelCell Energy system will operate directly on biogas from a nearby wastewater treatment plant. Microsoft plans to scale up this system upon successful demonstration. Meanwhile, AT&T has become the largest fuel cell customer in the U.S., announcing an additional 9.6 MW to accompany the 7.5 MW from last year. This adds up to 17.1 MW of fuel cells helping to power 28 AT&T sites in California and Connecticut, including data centers.

Top Fuel Cell Power Customers

1	at&t	**17.1 MW** at 28 sites
2	Walmart	**10.4 MW** at 26 sites
3	ebay	**6.5 MW** at 2 sites
4	Apple	**5.3 MW** at 2 sites
5	KAISER PERMANENTE	**5.0 MW** at 7 sites
6	Coca-Cola	**3.1 MW** at 4 sites
7	cox	**3.0 MW** at 5 sites
8	CBS	**2.4 MW** at 2 sites
9	Sheraton Hotels & Resorts	**2.3 MW** at 5 sites
10	Adobe	**1.6 MW** at 2 sites

Media

Also reliant on continuous power - especially in the age of 24/7 cable news coverage - many media outlets are turning to fuel cells to power studios and communications networks. CBS Studios recently purchased 2.4 MW of UTC Power fuel cell systems for two California production locations housing 26 sound stages between them. News Corporation, based in New York City, installed a 400-kW fuel cell to generate electricity for the TV studio, with the waste heat being captured for hot water.

Time Warner Cable installed an Altergy Systems' 30-kW fuel cell system to provide backup electrical power to its Palm Springs, California, distribution hub that receives television, high-speed data, and phone signals from its primary distribution center in Palm Desert, and then distributes them to residential and business customers throughout Palm Springs.

Materials Handling

The U.S. is now the undisputed world leader in fuel cell lift truck deployments, and is also the leading manufacturer of them. There are now fuel cell lift trucks deployed at facilities in 19 states, with more on the way. In the year since our last report, there have been many new deployments and orders of fuel cell-powered lift trucks, including several from previous customers such as Coca-Cola and BMW. New customers include Procter & Gamble, Kroger, and Lowe's. Several U.S. based fuel cell developers are cornering the materials handling market, and lift truck manufacturers and integrators, such as Crown, Raymond and Yale, are boosting sales by offering fuel cells in their catalogues.

The benefits to businesses deploying fuel cell lift trucks are many. Longer run times, no voltage sag and faster refills mean more productivity from lift truck operators. No battery storage and changing room or dedicated employees manning it means more warehouse space for product, with some companies reporting recouping 6-7% of space upon switching to fuel cells. Zero-emission fuel cells are helping workers breathe easier around the warehouse as well.

Top Fuel Cell Lift Truck Customers

1	Sysco	**700+ forklifts** at 7 sites
2	Walmart	**509 forklifts** at 3 sites
3	P&G	**340 forklifts** at 4 sites
4	central grocers	**234 forklifts** at 1 site
5	BMW	**230+ forklifts** at 1 site
6	WinCo Foods	**200+ forklifts** at 1 site
7	Kroger	**161 forklifts** at 1 site
8	Lowe's	**161 forklifts** at 1 site
9	Wegmans	**140+ forklifts** at 1 site
10	Coca-Cola	**96 forklifts** at 2 sites

Real Estate/Hospitality

Fuel cells have been checking into hotels for years now, with the first installation in the early 1990s. Since then, there have been fuel cells installed in hotels and casinos around the country, and increasingly, in other real estate developments such as high rise office buildings, mixed-use apartment buildings and office parks. In February 2012, JMB Realty's Constellation Place (formerly MGM Tower) became the first Los Angeles skyscraper to be powered by fuel cells.

Fuel cells are inherently efficient, and when the heat is captured and used, that efficiency total more than 90%. This captured heat can be used in many capacities in the hospitality setting – hot water, space heating, even for the pool or sauna. For some hotels, preserving historical buildings while upgrading energy systems can be a tricky situation. Fuel cells can be sited indoors or out, on roofs or in basements, and have a much smaller footprint than other technologies, so many developers are now designing them into the décor, including most recently at the historic Lafayette Hotel in San Diego.

III. Distributed Generation

The U.S. electric grid is 99.97% reliable, yet that 0.03% of unreliability is both troublesome and costly. In fact, the U.S. Department of Energy (DOE) reports that grid power outages and power quality issues cost American businesses on average over $100 billion each year.[2]

The threat of a cyber attack against critical infrastructure has emerged as yet another challenge to grid security in recent years, potentially impacting the information technology (IT) systems and networks used within the electric utility and delivery infrastructure, such as power lines, electricity control systems, and customer meters. A July 2012 Government Accountability (GAO) report[3] examined the growth of these threats to the electric power industry and states that this is one of the nation's high-risk vulnerabilities.

AVERAGE COST FOR ONE HOUR OF POWER INTERRUPTION

Cellular communications	$41,000
Telephone ticket sales	$72,000
Airline reservation system	$90,000
Semiconductor manufacturer	$2,000,000
Credit card operation	$2,580,000
Brokerage operation	$6,480,000

Source: U.S. Department of Energy [The Smart Grid: An Introduction.]

Fuel cell systems, whether grid-tied or grid-independent, provide premium power without voltage sags, surges, and frequency variations that can impact computer systems. In addition to power, byproduct heat from a fuel cell can be used at the end-user facility for space heating, water heating, and chilling. When supplementing grid power, fuel cells reduce peak demand and lower energy bills. In some areas, fuel cell power is even cheaper than grid electricity. Power purchase agreements, offered by many of the major fuel cell companies, can lock in the cost of fuel cell power for a specified period, generating cost savings over the term of the contract (more detail on page 10). On top of everything, fuel cells produce little to no polluting emissions – making fuel cells the cleanest energy generation technology available today.

IV. Partners in Power

Fuel cell systems can be scaled up to multi-megawatts and are capable of taking entire corporate campuses off the electric grid, but they do not have to work alone. In fact, many facilities now use fuel cells alongside other energy technologies to meet their power needs. Companies with critical power needs, ambitious sustainability goals, or both, have paired fuel cells with other renewable sources of energy such as solar, biogas, and wind to achieve serious emissions reductions and hardened grid independence. In other cases, fuel cells enhance conventional technologies and fuels such as batteries and natural gas, boosting the efficiency and extending the life, helping companies get more from less. The following section highlights the versatility of fuel cell technology and how it pairs with familiar energy sources and technology.

The New York Times

June 24, 2010

Another U.S. Clean Energy Generator Finds a Home Abroad

By DARIUS DIXON of ClimateWire

A decade ago, Americans were fascinated with the idea of a hydrogen-powered economy. The George W. Bush administration projected images of millions of cars zipping down the highway, pumping out nothing but water for exhaust from their fuel cell engines. That future is still a long way off, but the technology for high-efficiency fuel cell power plants could be here today, if only the right policies were in place to bring it to the mainstream.

That was part of the message at a technology workshop hosted earlier this week by the U.S. Energy Association and its executive director, Barry Worthington. USEA is a collection of interested groups ranging from oil companies and power utilities to universities and federal agencies.

The other part of the message is that countries that provide the right incentives and take the necessary risks can be the first to push clean technology into commercial development. In the case of solar and wind energy -- both first developed in the United States -- it was Europe and Japan that turned them into major electricity producers.

In the case of the fuel cell power plant, it is South Korea that is now leading the way.

In principle, fuel cells are designed much like a normal battery: two electrodes on either end separated by a material that allows charge to move between them. Instead of burning the natural gas for energy, fuel cells use an electrochemical process that breaks down molecules that contain hydrogen and recombines them differently, creating an electrical current in the process.

Applause from Calif.

The challenge for researchers over the years has been to find the most efficient way to achieve the current. For decades, DOE has encouraged the commercialization of fuel cell technology for power plants. In partnership with Connecticut-based FuelCell Energy Inc., it has developed a molten carbonate fuel cell, which the company has incorporated into its so-called Direct FuelCell, or DFC.

While fuel cells designed for vehicles use hydrogen derived from natural gas, the DFCs can use an array of different fuels, including coal gas, ethanol and waste biogas, in addition to natural gas.

FuelCell Energy said the company performs all of its manufacturing and research and development in Connecticut, but when an order comes in, a team is sent to the site to install the power plants themselves.

California's strict air emissions standards have played out favorably for FuelCell Energy, making the state the company's second-largest market. Because fuel cells do not use combustion and do not produce particulate matter or smog-contributing gases, the California Air Resources Board categorized FuelCell Energy's DFC power plants as an ultraclean technology. This exempted the power plants from air pollution control or air quality permitting requirements.

California's Self-Generation Incentive Program also provides financial incentives for certain fuel cell projects with the goal of reducing greenhouse gas emissions. Andrew Schwartz, a chief energy adviser for the California Public Utilities Commission, attended the USEA workshop to discuss his state's interest in the technology.

Orders from South Korea

But despite some interest in California and many parts of the world, FuelCell Energy's biggest orders have come pouring in from South Korea.

FuelCell Energy installed 32.8 megawatts in the fiscal year that ended Oct. 31, 2009, according to the company's filings with the Securities and Exchange Commission. "[W]e installed 23 MW of our MW-class power plants in South Korea," the filing read. "Half our current worldwide installed base."

South Korea feeds nearly 97 percent of its fuel requirements with imports, said Tae-Hyoung Kim, a strategic planning and marketing manager with South Korea's largest independent power company, POSCO Power Inc. The 14th-largest economy in the world, South Korea is also the world's ninth-largest emitter of carbon dioxide, according to statistics from the U.S. Department of Energy. And in 2007, little more than 1 percent of the country's electricity generation came from renewable sources.

Despite its great dependence on fossil fuels, South Korea was decidedly absent while other developed economies pushed for renewable energy, Kim said. Europeans have cornered the market on wind energy, while China and Japan have a significant presence in the solar industry. South Korea, he said, hopes to become a major energy innovator through fuel cell technology.

The South Korean government has also turned its attention towards renewable energy in a substantial way.

Recent national legislation aims to bring electricity generated by "new and renewable sources" to 4 percent by 2015 and 11 percent by 2030. The South Korean government has also provided clean and renewable energy subsidies and feed-in tariffs that would allow excess energy to be sold to the electricity grid.

Kim explained how fuel cells reached the top of POSCO's energy list: South Korea is too mountainous to reasonably install additional solar panels or wind turbines and the accompanying transmission lines, he said, and the coastline is too deep to set up wave energy technology. So the next best way to pivot the energy economy was to find new ways to maximize efficiency.

A strong partner focused on the Asian market

In February 2007, FuelCell Energy signed a 10-year manufacturing and distribution agreement with POSCO for DFC power plant distribution in South Korea. Then, last October, FuelCell Energy made a licensing agreement with POSCO that would allow the Korean company to "assemble and manufacture fuel cell modules using components manufactured or supplied by FuelCell Energy." The agreement basically protects the manufacturing base of FuelCell Energy, in Connecticut, while expanding and supplying its Asian market.

The two companies may be joined at the hip for quite some time. Late last year, POSCO purchased 13 percent of FuelCell Energy's common stock.

Given FuelCell Energy's small customer base, the SEC filing said, the company has made itself somewhat vulnerable. POSCO's stock ownership, FuelCell Energy said, "could make it difficult for a third party to acquire our common stock."

Sales to POSCO, DOE and other government agencies accounted for 80 percent of FuelCell Energy's total revenue in its most recent fiscal year, a figure up from 62 percent the year before.

FuelCell Energy also remarked on the combination of POSCO's purchase of company stock and its position as a license holder on the fuel cell technology as well as a major purchaser of its products, saying "it may be in their interests to possess substantial influence over matters concerning our overall strategy and technological and commercial development."

There are 55 operating FuelCell Energy power plants, according to company records. Installations include wastewater treatment plants in California, a Pepperidge Farm factory in Connecticut and a power plant that uses waste digestive gases emanating from Kirin Brewery Co. in Tokyo.

FuelCell Energy also partnered with Enbridge Inc., a major North American natural gas pipeline company based in Ontario, to develop a 2.2-megawatt fuel cell power plant, enough to power 1,700 homes in the Toronto area.

The biggest challenges facing the fuel cell industry, FuelCell Energy Vice President Frank Wolak told workshop attendees, are pushing an entrenched utility industry to do something new, and, as with any new technology, the cost.

ISSUES ONLINE IN SCIENCE AND TECHNOLOGY

A Publication of
National Academy of Sciences
National Academy of Engineering
Institute of Medicine
University of Texas at Dallas

ENVIRONMENT & ENERGY

ALVIN M. WEINBERG

New Life for Nuclear Power

Most of what I wrote in "Engineering in an Age of Anxiety" and "Energy Policy in an Age of Uncertainty" I still believe: Inherently safe nuclear energy technologies will continue to evolve; total U.S. energy output will rise more slowly than it has hitherto; and incrementalism will, at least in the short run, dominate our energy supply. However, my perspective has changed in some ways as the result of an emerging development in electricity generation: the remarkable extension of the lifetimes of many generating facilities, particularly nuclear reactors. If this trend continues, it could significantly alter the long-term prospect for nuclear energy.

This trend toward nuclear reactor "immortality" has become apparent in the past 20 years, and it has become clear that the projected lifetime of a reactor is far longer than we had estimated when we licensed these reactors for 30 to 40 years. Some 14 U.S. reactors have been relicensed, 16 others have applied for relicensing, and 18 more applications are expected by 2004. According to former Nuclear Regulatory Commission Chairman Richard Meserve, essentially all 103 U.S. power reactors will be relicensed for at least another 20 years.

If nuclear reactors receive normal maintenance, they will "never" wear out, and this will profoundly affect the economic performance of the reactors. Time annihilates capital costs. The economic Achilles' heel of nuclear energy has been its high capital cost. In this respect, nuclear energy resembles renewable energy sources such as wind turbines, hydroelectric facilities, and

Making a significant contribution to CO_2 control would require a roughly photovoltaic cells, which have high capital costs but low operating expenses. If a reactor lasts beyond its amortization time, the burden of debt falls drastically. Indeed, according to one estimate, fully amortized nuclear reactors with total electricity production costs (operation and maintenance, fuel, and capital costs) below 2 cents per kilowatt hour are possible.

10-fold increase in the world's nuclear capacity.

Electricity that inexpensive would make it economically feasible to power operations such as seawater desalinization, fulfilling a dream that was common in the early days of nuclear power. President Eisenhower proposed building nuclear-powered industrial complexes in the West Bank as a solution to the Middle East's water problem, and Sen. Howard Baker promulgated a "sense of the U.S. Senate" resolution authorizing a study of such complexes as part of a settlement of the Israel-Palestinian conflict.

If power reactors are virtually immortal, we have in principle achieved nuclear electricity "too cheap to meter." But there is a major catch. The very inexpensive electricity does not kick in until the reactor is fully amortized, which means that the generation that pays for the reactor is giving a gift of cheap electricity to the next generation. Because such altruism is not likely to drive investment, the task becomes to develop accounting or funding methods that will make it possible to build the generation capacity that will eventually be a virtually permanent part of society's infrastructure.

If the only benefit of these reactors is to produce less expensive electricity and the market is the only force driving investment, then we will not see a massive investment in nuclear power. But if immortal reactors by their very nature serve purposes that fall outside of the market economy, their original capital cost can be handled in the way that society pays for infrastructure.

Such a purpose has emerged in recent years: the need to limit CO_2 emissions to protect against climate change. To a remarkable degree, the incentive to go nuclear has shifted from meeting future energy demand to controlling CO_2. At an extremely low price, electricity uses could expand to include activities such as electrolysis to produce hydrogen. If the purpose of building reactors is CO_2 control rather than producing electricity, then the issue of going nuclear is no longer a matter of simple economics. Just as the Tennessee Valley Authority's (TVA's) system of dams is justified by the public good of flood control, the system of reactors would be justified by the public good of CO_2 control. And just as TVA is underwritten by the government, the future expansion of nuclear energy could, at the very least, be financed by federally guaranteed loans. Larry Foulke, president of the American Nuclear Society, has proposed the creation of an Energy Independence Security Agency, which would underwrite the construction of nuclear reactors whose primary purpose is to control CO_2.

Making a significant contribution to CO_2 control would require a roughly 10-fold increase in the world's nuclear capacity. Providing fissile material to fuel these thousands of reactors for an indefinite period would require the use of breeder reactors, a technology that is already available; or the extraction of uranium from seawater, a technology yet to be developed.

Is the vision of a worldwide system of as many as 4,000 reactors to be taken seriously? In 1944, Enrico Fermi himself warned that the future of nuclear energy depended on the public's acceptance of an energy source encumbered by radioactivity and closely linked to the production of nuclear weapons. Aware of these concerns, the early advocates of nuclear power formulated the Acheson-Lilienthal plan, which called for rigorous control of all nuclear activities by the International Atomic Energy Agency (IAEA). But is this enough to make the public willing to accept 4,000 large reactors? Princeton University's Harold Feiveson has already said that he would rather forego nuclear energy than accept the risk of nuclear weapons proliferation in a 4,000-reactor world.

I cannot concede that our ingenuity is unequal to living in a 4,000-reactor world. With thoughtful planning, we could manage the risks. I imagine having about 500 nuclear parks, each of which would have up to 10 reactors plus reprocessing facilities. The parks would be regulated and guarded by a much-strengthened IAEA.

What about the possibility of another Chernobyl? Certainly today's reactors are safer than yesterday's, but the possibility of an accident is real. Last year, alarming corrosion was found at Ohio's Davis Besse plant, apparently the result of a breakdown in the management and operating practices at the plant. Chernobyl and Davis Besse illustrate the point of Fermi's warning: Although nuclear energy has been a successful technology that now provides 20 percent of U.S. electricity, it is a demanding technology.

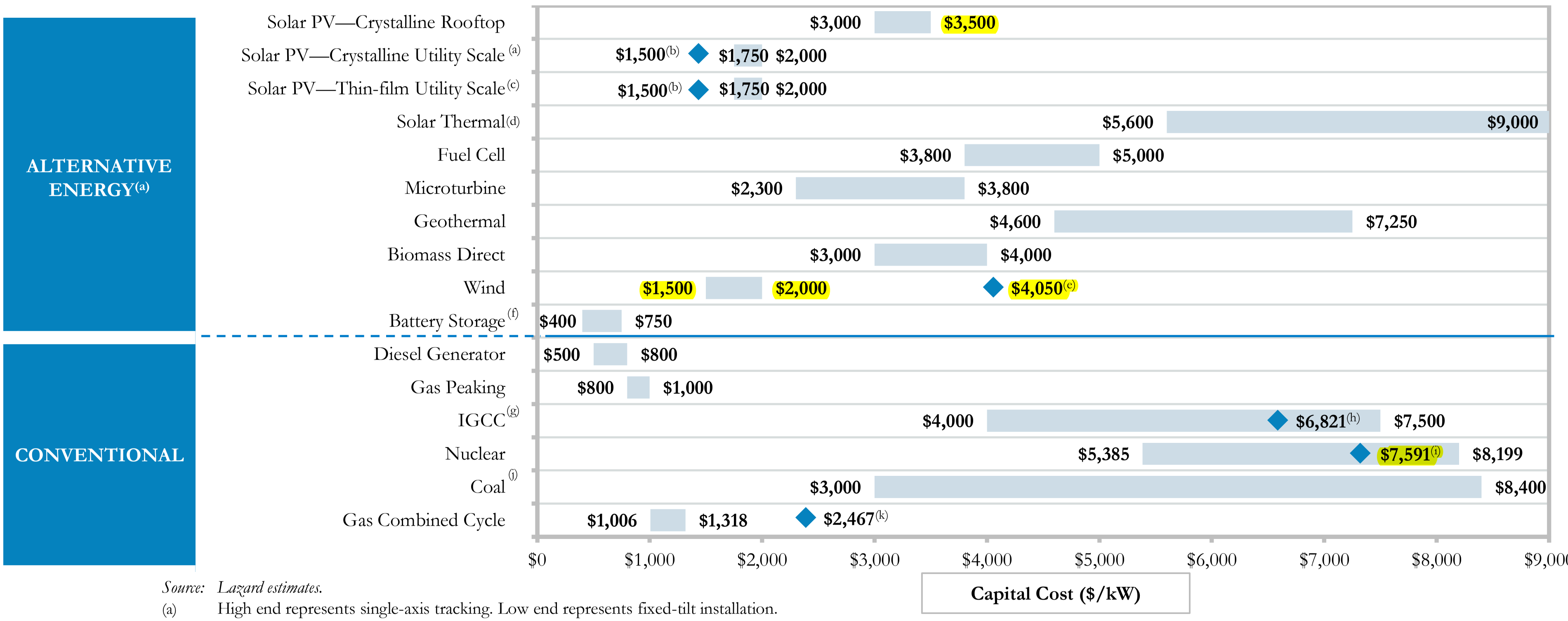
In addition to the risk of accidents, we face a growing possibility that nuclear material could fall into the hands of rogue states or terrorist groups and be used to create nuclear weapons. I disagree with Feiveson's conclusion that this risk is too great to bear. I believe that we can provide adequate security for 500 nuclear parks.

Is all this the fantasy of an aging nuclear pioneer? Possibly so. In any case, I won't be around to see how the 21st century deals with CO_2 and nuclear energy. Nevertheless, this much seems clear: If we are to establish a proliferation-proof fleet of 500 nuclear parks, we will have to expand on the Acheson-Lillienthal plan in ways that will--as George Schultz observed in 1989--require all nations to relinquish some national sovereignty.

Alvin M. Weinberg is a former director of the Oak Ridge National Laboratory.

Capital Cost Comparison

While capital costs for a number of Alternative Energy generation technologies (e.g., solar PV, solar thermal) are currently in excess of some conventional generation technologies (e.g., gas), declining costs for many Alternative Energy generation technologies, coupled with rising long-term construction and uncertain long-term fuel costs for conventional generation technologies, are working to close formerly wide gaps in electricity costs. This assessment, however, does not take into account issues such as dispatch characteristics, capacity factors, fuel and other costs needed to compare generation technologies



Source: Lazard estimates.

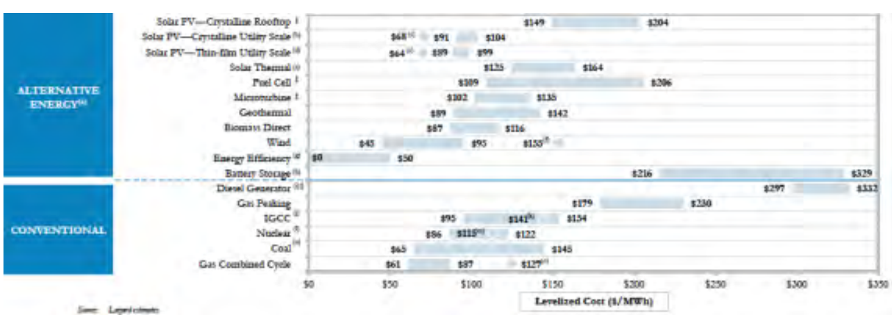
(a) High end represents single-axis tracking. Low end represents fixed-tilt installation.
(b) Diamonds represent estimated capital costs in 2015, assuming $1.50 per watt for a crystalline single-axis tracking system and $1.50 per watt for a thin-film single-axis tracking system.
(c) High end represents single-axis tracking. Low end represents fixed-tilt installation.
(d) Low end represents solar tower without storage. High end represents solar tower with storage capability.
(e) Represents estimated midpoint of capital costs for offshore wind, assuming a range of $3.10 – $5.00 per watt.
(f) Indicative range based on current and future stationary storage technologies.
(g) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.
(h) Represents estimate of current U.S. new IGCC construction with carbon capture and compression. Does not include cost of transportation and storage.
(i) Represents estimate of current U.S. new nuclear construction.
(j) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.
(k) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

Analysis: 50% Reduction In Cost Of Renewable Energy Since 2008

Renewable energy becoming more cost-competitive with fossil fuels isn't news – as technology improves and more clean power generation comes online, electricity without emissions gets cheaper. But one new analysis reveals just how shockingly cheap it's gotten.

The levelized cost of electricity (LCOE) from wind and solar sources in America has fallen by more than 50% over the past four years, according to ***Lazard's Levelized Cost of Energy Analysis 7.0***, recently released by global financial advisor and asset manager firm Lazard Freres & Co.

Lazard's analysis compared the **LCOE for various renewable energy technologies** to fossil fuels on a cost per megawatt hour (MWh) basis, including factors like US federal tax subsidies, fuel costs, geography, and capital costs.



Unsubsidized LCOE for US energy graph via Lazard

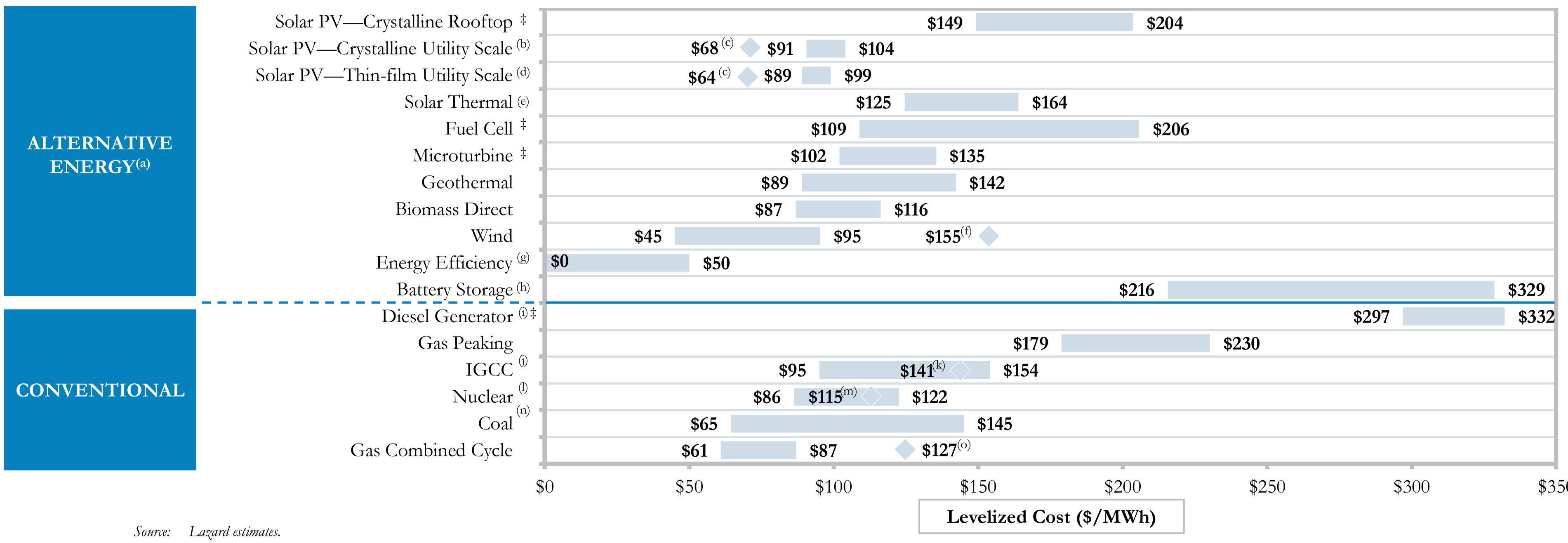
Utility-Scale Solar, Wind Lead LCOE Charge

The LCOE analysis shows that even during one of the most turbulent times in recent memory for renewables, the environmental and economic benefits of clean energy continue to spur technological innovations and utility-scale deployments across the globe.

According to the analysis, utility-scale **solar photovoltaics** (PV) and leading types of **wind energy** are leading the surge – the LCOE of both power sources has fallen by more than

Unsubsidized Levelized Cost of Energy Comparison

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios, before factoring in environmental and other externalities (e.g., RECs, transmission and back-up generation/system reliability costs) as well as construction and fuel cost dynamics affecting conventional generation technologies



Source: *Lazard estimates.*

Note: Assumes 60% debt at 8% interest rate and 40% equity at 12% cost for conventional and Alternative Energy generation technologies. Assumes Powder River Basin coal price of $1.99 per MMBtu and natural gas price of $4.50 per MMBtu. As many have argued, current solar pricing trends may be masking material differences between the inherent economics of certain types of thin-film technologies and crystalline silicon.

‡ Denotes distributed generation technology.

(a) Analysis excludes integration costs for intermittent technologies. A variety of studies suggest integration costs ranging from $2.00 to $10.00 per MWh.

(b) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW system in high insolation jurisdiction (e.g., Southwest U.S.). Not directly comparable for baseload.

(c) Diamonds represent estimated implied levelized cost of energy in 2015, assuming $1.50 per watt for a crystalline single-axis tracking system and $1.50 per watt for a thin-film single-axis tracking system.

(d) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW fixed-tilt installation in high insolation jurisdiction (e.g., Southwest U.S.).

(e) Low end represents solar tower without storage. High end represents solar tower with storage capability.

(f) Represents estimated midpoint of levelized cost of energy for offshore wind, assuming a range of $3.10 – $5.00 per watt.

(g) Estimates per National Action Plan for Energy Efficiency; actual cost for various initiatives varies widely. Estimates involving demand response may fail to account for opportunity cost of foregone consumption.

(h) Indicative range based on current and future stationary storage technologies; assumes capital costs of $400 – $750/KWh for 6 hours of storage capacity, $60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 66% – 75% and fixed O&M costs of $5 to $20 per KWh installed per year.

(i) Low end represents continuous operation. High end represents intermittent operation. Assumes diesel price of $4.00 per gallon.

(j) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(k) Represents estimate of current U.S. new IGCC construction with carbon capture and compression. Does not include cost of transportation and storage.

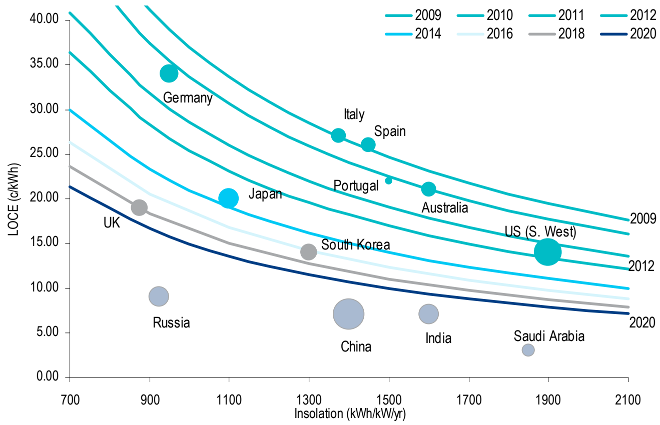
(l) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.

(m) Represents estimate of current U.S. new nuclear construction.

(n) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

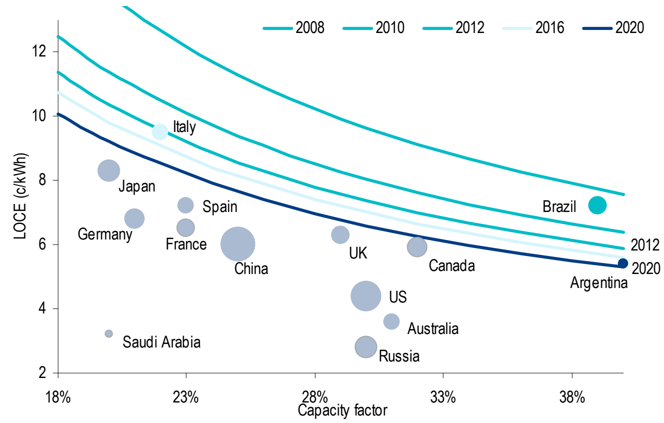
(o) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

Figure 6. Solar is already competitive vs. domestic electricity prices for many countries, with many more to follow soon



Source: Bloomberg New Energy Finance, Citi Research

Figure 7. Wind has a tougher benchmark – it has to compete with low wholesale prices, but is very nearly there without subsidies



Source: Bloomberg New Energy Finance, Citi Research

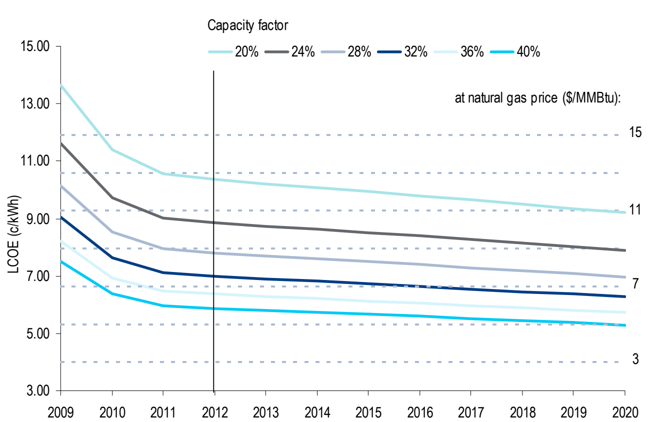
Solar and wind are at parity or nearly there in many countries…

What is clear is that the perception of renewable technologies as being inefficient and requiring material subsidies is no longer accurate. Solar is already cheaper than electricity at the plug in many countries, with others very close behind, and while wind has a tougher deal having to compete with lower wholesale (rather than domestic) prices, it too is nearly there without subsidies.

...and can even compete with gas in a growing number of countries

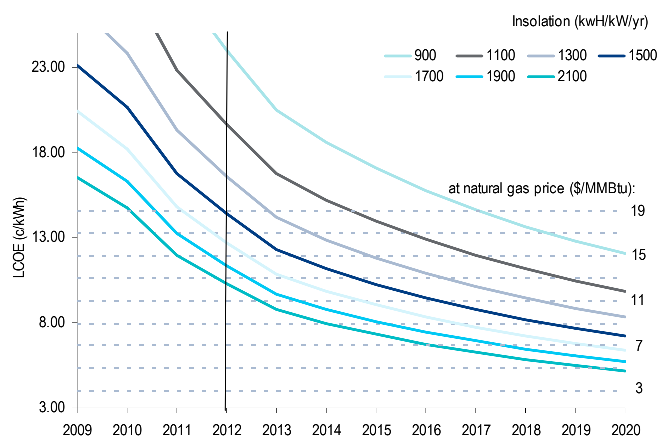
But surely they can't compete with shale? We have analysed in detail the impact of gas costs (and hence shale) on the price of electricity generated from CCGTs, and then combined this with the renewable experience curve cost analysis. Reproducing the curves for different levels of wind and solar resource (i.e. by country) results in cost crossover charts below, which effectively show in what year solar and wind become competitive with CCGTs for a range of gas prices.

Figure 8. Wind is already cheaper than CCGT electricity in high-priced gas markets, and in windier regions can compete with cheap shale



Source: Citi Research

Figure 9. Utility scale solar competes now with CCGTs in sunny/high-priced gas regions, and will soon approach cheap shale



Source: Citi Research

So what does all this analysis mean? Put simply, vast cost reductions have made renewables already competitive vs. other energy sources in many parts of the world, and the fast learning rates mean that by 2020, renewables will be 'cutting it' in most parts of the world. So, we should view shale not as the demise of renewables, but rather as a lower-carbon transition fuel to a new age of renewables, which then itself requires greater use of gas peaking plant (replacing baseload).

When will renewables be cost-competitive with gas-fired power?

Whether the shale gas boom is a threat to investment in renewable energy depends, to a large degree, on the cost-competitiveness of renewable energy with gas-fired power. In order for gas-fired power to establish its credentials as a 'bridge-fuel' to a low-carbon future, it must offer significant cost advantages over renewables.

Renewable energy has reduced in cost dramatically, and should be competitive with gas-fired generation in many regions in the medium term

The perception of renewables as an expensive source of electricity is largely obsolete, given the huge cost reductions achieved in recent years. Residential solar PV has already reached 'grid parity' in regions of high solar insolation, with much of the world set to follow by 2020.

Our view is that utility-scale renewables will be competitive with gas-fired power in the short to medium term, with the exact 'crossover' points varying from country to country. In many regions, we believe competitiveness will be achieved by 2020.

Assessing competitiveness

To assess the competitiveness of solar power compared to gas-fired power, we use the 'levelised cost of electricity' (LCOE) as the relevant comparator. The LCOE quantifies the average cost of producing a unit of electricity from different sources of power.

To assess the LCOE of solar and wind power, the key input assumptions are

1. The system costs of the solar/wind installation; and

2. The quality and quantity of the solar/wind resource at the location of the installation – for solar this is measured by the solar insolation; for wind this is measured by the capacity factor,

with secondary input assumptions on the life-time of the wind/solar installation, operating costs (opex), degradation rate (only for solar) and the IRR.

To assess the LCOE of gas-fired power, the key input assumption is the natural gas costs for the power plant, with secondary input assumptions on the fixed and variable opex, the carbon price, the life-time of the gas-fired power plant and the assumed IRR.

In order to project LCOEs for solar, wind and gas-fired power forward into the future, we need to forecast both future system costs for a solar/wind plant and give scenarios for possible future natural gas costs.

How is LCOE calculated?

The LCOE is a measurement of the average cost of producing a unit of electricity over the life-time of the generating source, in this case either a gas-fired power plant or a solar installation.

The LCOE considers, on the one hand, the total quantity of electricity produced by the source, and on the other, the costs that went into establishing the source over its life-time, including the original capital expenditure, ongoing maintenance costs, the cost of fuel and any carbon costs.

The LCOE also takes into account the financing costs of the project, both deducting the cost of debt (for an appropriate level of debt-financing) and ensuring that the project generates a reasonable internal rate of return (IRR) for the equity providers.

Environmental Science & Technology

Correspondence/Rebuttal

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Comment on "Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power"

Pushker Kharecha and James Hansen have made a contribution in their article about the benefits of nuclear power.[1] However, issues of technology systems integration deserve added attention as well as addressing a few errors. Though there is some logic underpinning the notion that nuclear power can mitigate greenhouse gas emissions as a "stabilization wedge",[2] we argue that (a) its near-term potential is significantly limited compared to energy efficiency and renewable energy; (b) it displaces emissions and saves lives only at high cost and at the enhanced risk of nuclear weapons proliferation; (c) it is unsuitable for expanding access to modern energy services in developing countries; and (d) the authors' estimates of cancer risks from exposure to radiation are flawed.

First, nuclear power reactors are less effective at displacing greenhouse gas emissions than energy efficiency initiatives and renewable energy technologies. According to one early study, each dollar invested in energy efficiency displaces nearly 7 times as much carbon dioxide as a dollar invested in nuclear power.[3] McKinsey & Company's cost abatement curves have repeatedly affirmed this point, concluding that nuclear power is a significantly more expensive mitigation option than investments in efficiency, waste recycling, geothermal, and small hydroelectric dams, among others.[4]

Part of the explanation is that some countries enrich uranium with coal-fired power and have low reactor capacity factors, meaning the greenhouse gas emissions from their lifecycle can rival that of natural gas.[5] Another part of the explanation is that nuclear power plants have substantial opportunity costs—construction delays, cost overruns, and the like—that add to their carbon footprints—figures reflected in Table 1 below.[6] According to this table, on a lifecycle equivalent carbon dioxide basis wind energy is *twenty four* times as effective at displacing emissions per kWh and hydroelectricity is roughly *twice* as effective.

Second, even if nuclear energy could save lives, it does so at a substantially higher financial, environmental, and political cost than alternatives. As Table 1 also reveals, when recent marginal capital and levelized costs are factored in for the United States, wind energy is 96 times more effective at displacing carbon than nuclear power; other renewable sources range from about 20 times to twice as effective. Indeed, The U.S. Congressional Budget Office estimated nuclear power plant construction costs from 1966 to 1977, when most light water reactors in the U.S. were built, and found that the quoted cost for these 75 plants was $89.1 billion, but the real cost was $283.3 billion.[7] These cost overruns have every likelihood of affecting future plants.[8−11]

Nuclear power therefore needs significant subsidies in order to "compete" in the marketplace.[12] Douglas Koplow looked at five decades worth of subsidies data and concluded that "subsidies to the nuclear fuel cycle have often exceeded the value of the power produced. This means that buying power on the open market and giving it away for free would have been less costly than subsidizing the construction and operation of nuclear power plants".[13] Such reliance on subsidies caused Peter Bradford, a former regulator at the NRC, to observe that the best way to phase out nuclear energy would be to simply "do nothing".[14] New reactors today never prevail in competitive power procurement processes anywhere in the world.

Furthermore, these are only the direct financial costs of nuclear power—they do not include serious environmental degradation from uranium mining and milling,[15] nor do they factor in the water intensity of nuclear power and its inability to operate during water shortages and droughts.[16] In fact, according to the NRC's S3 table on impacts of the nuclear fuel cycle, by far the largest public exposure to radiation comes from the radon released by uranium mining and mill tailings.

The authors exclude macroeconomic property damage and evacuation costs from accidents such as Chernobyl and Fukushima.[17] Kharecha and Hansen ignore the serious issue of nuclear waste storage,[18] and that of nuclear proliferation.[19] To date, several countries have tried or succeeded in developing nuclear weapons under the guise of civilian nuclear weapons programs. If we doubled the number of nuclear reactors worldwide, many countries without weapons might obtain them. There is no such catastrophic risk associated with efficiency and renewables.

Third, nuclear power as currently structured is nonviable for most emerging economies and developing countries. Small island developing states such as Fiji or the Maldives, and least developed countries such as Bhutan or Mali, have entire electricity sectors with only a few hundred million dollars of investment and small amounts of installed capacity. How are they to afford the billions needed for a commercial reactor? Moreover, corruption and challenges in securing nuclear power establishments in some nations radically elevate the risk of terrorists gaining access to nuclear materials. The best energy option for these countries is to expand access to improved cookstoves, microhydro dams, solar home systems, and microgrids [20] rather than nuclear technology. For instance, in India $2 billion can be spent on a single new nuclear reactor, *or* it could provide 114 million households at the "bottom of the pyramid" with solar lanterns, cookstoves, and small hydropower systems.[21]

Fourthly, Kharecha and Hansen have chosen to go against the prevailing scientific consensus and chosen to use the lowest possible estimates of Chernobyl mortalities, unhinging their conclusions. For sure, there are uncertainties involved, but as the 2006 report of UNSCEAR concluded, "the inability to detect increases in risks at very low doses using epidemiological methods does not mean that the cancer risks are not elevated".[22] The U.S. National Research Council's Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation (BEIR Committee) went a step further.

Published: May 22, 2013

PART I: AP IMPACT: US nuke regulators weaken safety rules

By JEFF DONN

LACEY TOWNSHIP, N.J. (AP) — Federal regulators have been working closely with the nuclear power industry to keep the nation's aging reactors operating within safety standards by repeatedly weakening those standards, or simply failing to enforce them, an investigation by The Associated Press has found.

Time after time, officials at the U.S. Nuclear Regulatory Commission have decided that original regulations were too strict, arguing that safety margins could be eased without peril, according to records and interviews.

The result? Rising fears that these accommodations by the NRC are significantly undermining safety — and inching the reactors closer to an accident that could harm the public and jeopardize the future of nuclear power in the United States.

Examples abound. When valves leaked, more leakage was allowed — up to 20 times the original limit. When rampant cracking caused radioactive leaks from steam generator tubing, an easier test of the tubes was devised, so plants could meet standards.

Failed cables. Busted seals. Broken nozzles, clogged screens, cracked concrete, dented containers, corroded metals and rusty underground pipes — all of these and thousands of other problems linked to aging were uncovered in the AP's yearlong investigation. And all of them could escalate dangers in the event of an accident.

Yet despite the many problems linked to aging, not a single official body in government or industry has studied the overall frequency and potential impact on safety of such breakdowns in recent years, even as the NRC has extended the licenses of dozens of reactors.

Industry and government officials defend their actions, and insist that no chances are being taken. But the AP investigation found that with billions of dollars and 19 percent of America's electricity supply at stake, a cozy relationship prevails between the industry and its regulator, the NRC.

Records show a recurring pattern: Reactor parts or systems fall out of compliance with the rules. Studies are conducted by the industry and government, and all agree that existing standards are "unnecessarily conservative."

Regulations are loosened, and the reactors are back in compliance.

"That's what they say for everything, whether that's the case or not," said Demetrios Basdekas, an engineer retired from the NRC. "Every time you turn around, they say 'We have all this built-in conservatism.'"

The ongoing crisis at the stricken, decades-old Fukushima Dai-ichi nuclear facility in Japan has focused attention on the safety of plants elsewhere in the world; it prompted the NRC to look at U.S. reactors, and a report is due in July.

But the factor of aging goes far beyond the issues posed by the disaster at Fukushima.

Commercial nuclear reactors in the United States were designed and licensed for 40 years. When the first ones were being built in the 1960s and 1970s, it was expected that they would be replaced with improved models long before those licenses expired.

But that never happened. The 1979 accident at Three Mile Island, massive cost overruns, crushing debt and high interest rates ended new construction proposals for several decades.

Instead, 66 of the 104 operating units have been relicensed for 20 more years, mostly with scant public attention. Renewal applications are under review for 16 other reactors.

By the standards in place when they were built, these reactors are old and getting older. As of today, 82 reactors are more than 25 years old.

The AP found proof that aging reactors have been allowed to run less safely to prolong operations. As equipment has approached or violated safety limits, regulators and reactor operators have loosened or bent the rules.

Last year, the NRC weakened the safety margin for acceptable radiation damage to reactor vessels — for a second time. The standard is based on a measurement known as a reactor vessel's "reference temperature," which predicts when it will become dangerously brittle and vulnerable to failure. Over the years, many plants have violated or come close to violating the standard.

As a result, the minimum standard was relaxed first by raising the reference temperature 50 percent, and then 78 percent above the original — even though a broken vessel could spill its radioactive contents into the environment.

"We've seen the pattern," said nuclear safety scientist Dana Powers, who works for Sandia National Laboratories and also sits on an NRC advisory committee. "They're ... trying to get more and more out of these plants."

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SHARPENING THE PENCIL

The AP collected and analyzed government and industry documents — including some never-before released. The examination looked at both types of reactor designs: pressurized water units that keep radioactivity confined to the reactor building and the less common boiling water types like those at Fukushima, which send radioactive water away from the reactor to drive electricity-generating turbines.

Tens of thousands of pages of government and industry studies were examined, along with test results, inspection reports and regulatory policy statements filed over four decades. Interviews were conducted with scores of managers, regulators, engineers, scientists, whistleblowers, activists, and residents living near the reactors, which are located at 65 sites, mostly in the East and Midwest.

AP reporting teams toured some of the oldest reactors — the unit here at Oyster Creek, near the Atlantic coast 50 miles east of Philadelphia, and two units at Indian Point, 25 miles north of New York City along the Hudson River.

Called "Oyster Creak" by some critics because of its aging problems, this boiling water reactor began running in 1969 and ranks as the country's oldest operating commercial nuclear power plant. Its license was extended in 2009 until 2029, though utility officials announced in December that they'll shut the reactor 10 years earlier rather than build state-ordered cooling towers. Applications to extend the lives of pressurized water units 2 and 3 at Indian Point, each more than 36 years old, are under review by the NRC.

Unprompted, several nuclear engineers and former regulators used nearly identical terminology to describe how industry and government research has frequently justified loosening safety standards to keep aging reactors within operating rules. They call the approach "sharpening the pencil" or "pencil engineering" — the fudging of calculations and assumptions to yield answers that enable plants with deteriorating conditions to remain in compliance.

"Many utilities are doing that sort of thing," said engineer Richard T. Lahey Jr., who used to design nuclear safety systems for General Electric Co., which makes boiling water reactors. "I think we need nuclear power, but we can't compromise on safety. I think the vulnerability is on these older plants."

Added Paul Blanch, an engineer who left the industry over safety issues but later returned to work on solving them: "It's a philosophical position that (federal regulators) take that's driven by the industry and by the economics: What do we need to do to let those plants continue to operate? They somehow sharpen their pencil to either modify their interpretation of the regulations, or they modify their assumptions in the risk assessment."

In public pronouncements, industry and government say aging is well under control. "I see an effort on the part of this agency to always make sure that we're doing the right things for safety. I'm not sure that I see a pattern of staff simply doing things because there's an interest to reduce requirements — that's certainly not the case," NRC chairman Gregory Jaczko said in an interview at agency headquarters in Rockville, Md.

Neil Wilmshurst, director of plant technology for the industry's Electric Power Research Institute, acknowledged that the industry and NRC often collaborate on research that supports rule changes. But he maintained that there's "no kind of misplaced alliance ... to get the right answer."

Yet agency staff, plant operators, and consultants paint a different picture in little-known reports, where evidence of industry-wide problems is striking:

—The AP reviewed 226 preliminary notifications — alerts on emerging safety problems — issued by the NRC since 2005. Wear and tear in the form of clogged lines, cracked parts, leaky seals, rust and other deterioration contributed to at least 26 alerts over the past six years. Other notifications lack detail, but aging also was a probable factor in 113 additional alerts. That would constitute up to 62 percent in all. For example, the 39-year-old Palisades reactor in Michigan shut Jan. 22 when an electrical cable failed, a fuse blew, and a valve stuck shut, expelling steam with low levels of radioactive tritium into the air outside. And a one-inch crack in a valve weld aborted a restart in February at the LaSalle site west of Chicago.

—One 2008 NRC report blamed 70 percent of potentially serious safety problems on "degraded conditions." Some involve human factors, but many stem from equipment wear, including cracked nozzles, loose paint, electrical problems, or offline cooling components.

—Confronted with worn parts that need maintenance, the industry has repeatedly requested — and regulators have often allowed — inspections and repairs to be delayed for months until scheduled refueling outages. Again and again, problems worsened before they were fixed. Postponed inspections inside a steam generator at Indian Point allowed tubing to burst, leading to a radioactive release in 2000. Two years later, cracking was allowed to grow so bad in nozzles on the reactor vessel at the Davis-Besse plant near Toledo, Ohio, that it came within two months of a possible breach, the NRC acknowledged in a report. A hole in the vessel could release radiation into the environment, yet inspections failed to catch the same problem on the replacement vessel head until more nozzles were found to be cracked last year.

TIME CRUMBLES THINGS

Nuclear plants are fundamentally no more immune to the incremental abuses of time than our cars or homes: Metals grow weak and rusty, concrete crumbles, paint peels, crud accumulates. Big components like 17-story-tall concrete containment buildings or 800-ton reactor vessels are all but impossible to replace. Smaller parts and systems can be swapped, but still pose risks as a result of weak maintenance and lax regulation or hard-to-predict failures. Even when things are fixed or replaced, the same parts or others nearby often fail later.

Even mundane deterioration at a reactor can carry harsh consequences.

For example, peeling paint and debris can be swept toward pumps that circulate cooling water in a reactor accident. A properly functioning containment building is needed to create air pressure that helps clear those pumps. The fact is, a containment building could fail in a severe accident. Yet the NRC has allowed operators to make safety calculations that assume containment buildings will hold.

In a 2009 letter, Mario V. Bonaca, then-chairman of the NRC's Advisory Committee on Reactor Safeguards, warned that this approach represents "a decrease in the safety margin" and makes a fuel-melting accident more likely. At Fukushima, hydrogen explosions blew apart two of six containment buildings, allowing radiation to escape from overheated fuel in storage pools.

Many photos in NRC archives — some released in response to AP requests under the federal Freedom of Information Act — show rust accumulated in a thick crust or paint peeling in long sheets on untended equipment at nuclear plants. Other breakdowns can't be observed or predicted, even with sophisticated analytic methods — especially for buried, hidden or hard-to-reach parts.

Industry and government reports are packed with troubling evidence of unrelenting wear — and repeated regulatory compromises.

Four areas stand out:

BRITTLE VESSELS: For years, operators have rearranged fuel rods to limit gradual radiation damage to the steel vessels protecting the core and to keep them strong enough to meet safety standards.

It hasn't worked well enough.

Even with last year's weakening of the safety margins, engineers and metal scientists say some plants may be forced to close over these concerns before their licenses run out — unless, of course, new compromises with regulations are made. But the stakes are high: A vessel damaged by radiation becomes brittle and prone to cracking in certain accidents at pressurized water reactors, potentially releasing its radioactive contents into the environment.

LEAKY VALVES: Operators have repeatedly violated leakage standards for valves designed to bottle up radioactive steam in the event of earthquakes and other accidents at boiling water reactors.

Many plants have found they could not adhere to the general standard allowing each of these parts — known as main steam isolation valves — to leak at a rate of no more than 11.5 cubic feet per hour. In 1999, the NRC decided to permit individual plants to seek amendments of up to 200 cubic feet per hour for all four steam valves combined.

But plants keep violating even those higher limits. For example, in 2007, Hatch Unit 2, in Baxley, Ga., reported combined leakage of 574 cubic feet per hour.

CRACKED TUBING: The industry has long known of cracking in steel alloy tubing originally used in the steam generators of pressurized water reactors. Ruptures were rampant in these tubes containing radioactive coolant; in 1993 alone, there were seven. Even today, as many as 18 reactors are still running on old generators.

Problems can arise even in a newer metal alloy, according to a report of a 2008 industry-government workshop.

CORRODED PIPING: Nuclear operators have failed to stop an epidemic of leaks in pipes and other underground equipment in damp settings. The country's nuclear sites have suffered more than 400 accidental radioactive leaks during their history, the activist Union of Concerned Scientists reported in September.

Plant operators have been drilling monitoring wells and patching hidden or buried piping and other equipment for several years to control an escalating outbreak.

Here, too, they have failed. Between 2000 and 2009, the annual number of leaks from underground piping shot up fivefold, according to an internal industry document obtained and analyzed by the AP.

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CONCERNS OF LONG STANDING

Even as they reassured the public, regulators have been worrying about aging reactors since at least the 1980s, when the first ones were entering only their second decade of operation. A 1984 report for the NRC blamed wear, corrosion, crud and fatigue for more than a third of 3,098 failures of parts or systems within the first 12 years of industry operations; the authors believed the number was actually much higher.

A decade later, in 1994, the NRC reported to Congress that the critical shrouds lining reactor cores were cracked at a minimum of 11 units, including five with extensive damage. The NRC ordered more aggressive maintenance, but an agency report last year said cracking of internal core components — spurred by radiation — remains "a major concern" in boiling water reactors.

A 1995 study by Oak Ridge National Laboratory covering a seven-year period found that aging contributed to 19 percent of scenarios that could have ended in severe accidents.

In 2001, the Union of Concerned Scientists, which does not oppose nuclear power, told Congress that aging problems had shut reactors eight times within 13 months.

And an NRC presentation for an international workshop that same year warned of escalating wear at reactor buildings meant to bottle up radiation during accidents. A total of 66 cases of damage were cited in the presentation, with corrosion reported at a quarter of all containment buildings. In at least two cases — at the two-reactor North Anna site 40 miles northwest of Richmond, Va., and the two-unit Brunswick facility near Wilmington, N.C. — steel containment liners designed to shield the public had rusted through.

And in 2009, a one-third-inch hole was discovered in a liner at Beaver Valley Unit 1 in Shippingport, Pa.

Long-standing, unresolved problems persist with electrical cables, too.

In a 1993 report labeled "official use only," an NRC staffer warned that electrical parts throughout plants were subject to dangerous age-related breakdowns unforeseen by the agency. Almost a fifth of cables failed in testing that simulated the effects of 40 years of wear. The report warned that as a result, reactor core damage could occur much more often than expected.

Fifteen years later, the problem appeared to have worsened. An NRC report warned in 2008 that rising numbers of electrical cables are failing with age, prompting temporary shutdowns and degrading safety. Agency staff tallied 269 known failures over the life of the industry.

Two industry-funded reports obtained by the AP said that managers and regulators have worried increasingly about the reliability of sometimes wet, hard-to-reach underground cables over the past five-to-10 years. One of the reports last year acknowledged many electrical-related aging failures at plants around the country.

"Multiple cable circuits may fail when called on to perform functions affecting safety," the report warned.

EATEN AWAY FROM WITHIN

Few aging problems have been more challenging than chemical corrosion from within.

In one of the industry's worst accidents, a corroded pipe burst at Virginia's Surry 2 reactor in 1986 and showered workers with scalding steam, killing four.

In summer 2001, the NRC was confronted with a new problem: Corrosive chemicals were cracking nozzles on reactors. But the NRC let operators delay inspections to coincide with scheduled outages. Inspection finally took place in February 2002 at the Davis-Besse unit in Ohio.

What workers found shocked the industry.

They discovered extensive cracking and a place where acidic boron had spurted from the reactor and eaten a gouge as big as a football. When the problem was found, just a fraction of an inch of inner lining remained. An NRC analysis determined that the vessel head could have burst within two months — what former NRC Commissioner Peter Bradford has called a "near rupture" which could have released large amounts of radiation into the environment.

In 2001-3 alone, at least 10 plants developed these cracks, according to an NRC analysis.

Industry defenders blame human failings at Davis-Besse. Owner FirstEnergy Corp. paid a $28 million fine, and courts convicted two plant employees of hiding the deterioration. NRC spokesman Scott Burnell declared that the agency "learned from the incident and improved resident inspector training and knowledge-sharing to ensure that such a situation is never repeated."

Yet on the same March day last year that Burnell's comments were released, Davis-Besse workers again found dried boron on the nozzles of a replacement vessel head, indicating more leaks. Inspecting further, they again found cracks in 24 of 69 nozzles.

"We were not expecting this issue," said plant spokesman Todd Schneider.

In August, the operator applied for a 20-year license extension. Under pressure from the NRC, the company has agreed to replace the replacement head in October.

As far back as the 1990s, the industry and NRC also were well aware that the steel-alloy tubing in many steam generators was subject to chemical corrosion. It could crack over time, releasing radioactive gases that can bypass the containment building. If too much spurts out, there may be too little water to cool down the reactor, prompting a core melt.

In 1993, NRC personnel reported seven outright ruptures inside the generators, several forced outages per year, and some complete replacements. Personnel at the Catawba plant near Charlotte, N.C., found more than 8,000 corroded tubes — more than half its total.

For plants with their original generators, "there is no end in sight to the steam generator tube degradation problems," a top agency manager declared. NRC staffers warned: "Crack depth is difficult to measure reliably and the crack growth rate is difficult to determine."

Yet no broad order was issued for shutdowns to inspect generators.

Instead, the staff began to talk to operators about how to deal with the standard that no cracks could go deeper than 40 percent through the tube wall.

In 1995, the NRC staff put out alternative criteria that let reactors keep running if they could reach positive results with remote checks known as "eddy-currents tests." The new test standard gave more breathing room to reactors.

According to a 2001 report by the Advisory Committee on Reactor Safeguards, the staff "acknowledged that there would be some possibility that cracks of objectionable depth might be overlooked and left in the steam generator for an additional operating cycle." The alternative, the report said, would be to repair or remove potentially many tubes from service.

NRC engineer Joe Hopenfeld, who had worked previously in the industry, challenged this approach at the time from within the agency. He warned that multiple ruptures in corroded tubing could release radiation. The NRC said radiation would be confined.

Hopenfeld now says this conclusion wasn't based on solid analysis but "wishful thinking" and research meant to reach a certain conclusion — another instance of "sharpening the pencil."

"It was a hard problem to solve, and they did not want to say it was a problem, because if they really said it was a problem, they would have to shut down a lot of reactors."

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AGE IS NO ISSUE, SAYS INDUSTRY

With financial pressures mounting in the 1990s to extend the life of aging reactors, new NRC calculations using something called the "Master Curve" put questionable reactor vessels back into the safe zone.

A 1999 NRC review of the Master Curve, used to analyze metal toughness, noted that energy deregulation had put financial pressure on nuclear plants. It went on: "So utility executives are considering new operational scenarios, some of which were unheard of as little as five years ago: extending the licensed life of the plant beyond 40 years." As a result, it said, the industry and the NRC were considering "refinements" of embrittlement calculations "with an eye to reducing known over-conservatisms."

Asked about references to economic pressures, NRC spokesman Burnell said motivations are irrelevant if a technology works.

Former NRC commissioner Peter Lyons said, "There certainly is plenty of research ... to support a relaxation of the conservativisms that had been built in before. I don't see that as decreasing safety. I see that as an appropriate standard."

Though some parts are too big and too expensive to replace, industry defenders also point out that many others are routinely replaced over the years.

Tony Pietrangelo, chief nuclear officer of the industry's Nuclear Energy Institute, acknowledges that you'd expect to see a growing failure rate at some point — "if we didn't replace and do consistent maintenance."

In a sense, then, supporters of aging nukes say an old reactor is essentially a collection of new parts.

"When a plant gets to be 40 years old, about the only thing that's 40 years old is the ink on the license," said NRC chief spokesman Eliot Brenner. "Most, if not all of the major components, will have been changed out."

Oyster Creek spokesman David Benson said the reactor "is as safe today as when it was built."

Yet plant officials have been trying to arrest rust on its 100-foot-high, radiation-blocking steel drywell for decades. The problem was declared solved long ago, but a rust patch was found again in late 2008. Benson said the new rust was only the size of a dime, but acknowledged there was "some indication of water getting in."

In an effort to meet safety standards, aging reactors have been forced to come up with backfit on top of backfit.

As Ivan Selin, a retired NRC chairman, put it: "It's as if we were all driving Model T's today and trying to bring them up to current mileage standards."

For example, the state of New Jersey — not the NRC — had ordered Oyster Creek to build cooling towers to protect sea life in nearby Barnegat Bay. Owner Exelon Corp. said that would cost about $750 million and force it to close the reactor — 20-year license extension notwithstanding. Even with the announcement to close in 2019, Oyster Creek will have been in operation for 50 years.

Many of the safety changes have been justified by something called "risk-informed" analysis, which the industry has employed widely since the 1990s: Regulators set aside a strict check list applied to all systems and focus instead on features deemed to carry the highest risk.

But one flaw of risk-informed analysis is that it doesn't explicitly account for age. An older reactor is not viewed as inherently more unpredictable than a younger one. Ed Lyman, a physicist with the Union of Concerned Scientists, says risk-informed analysis has usually served "to weaken regulations, rather than strengthen them."

Even without the right research, the NRC has long reserved legal wiggle room to enforce procedures, rules and standards as it sees fit. A 2008 position paper by the industry group EPRI said the approach has brought "a more tractable enforcement process and a significant reduction in the number of cited violations."

But some safety experts call it "tombstone regulation," implying that problems fester until something goes very wrong. "Until there are tombstones, they don't regulate," said Blanch, the longtime industry engineer who became a whistleblower.

Barry Bendar, a database administrator who lives one mile from Oyster Creek, said representatives of Exelon were asked at a public meeting in 2009 if the plant had a specific life span.

"Their answer was, 'No, we can fix it, we can replace, we can patch,'" said Bendar. "To me, everything reaches an end of its life span."

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CHAPTER 3. TRENDS FROM NEAR-MISSES 2010-2012

This chapter describes our analysis of the data from the nuclear reactor near-misses reported in our 2010, 2011, and 2012 reports.

As presented in Table 4, 56 near-misses were reported at 40 different reactors over this three year period. The number of reactors experiencing near-misses remained fairly constant year to year: 18 in 2010, 17 in 2011, and 16 in 2012.[6] Over this three-year period, nearly 40 percent of U.S. reactors experienced a near-miss.

That 56 near-misses occurred at 40 reactors means some reactors are repeat offenders. Table 4 shows that Wolf Creek tops the frequent offender list with four near-misses over three years. In fact, Wolf Creek experienced at least one near-miss each year.

The Palisades and Fort Calhoun reactors tied for second with three near-misses in three years.

From the glass half-full perspective, 64 of the nation's 104 reactors did not experience a near-miss between 2010 and 2012. If performance during this three-year period is representative of overall industry performance, however, then it may only be a matter of time before near-misses occur at those reactors as well.

The 2010-2012 data indicate the "average" reactor has a roughly one-in-six chance each year that it will experience a near-miss. With reactors originally licensed for 40 years and most being relicensed for an additional 20 years, that rate—if sustained—means the typical reactor could experience 7 near-misses over its 40-year lifetime and about 10 near-misses over 60 years.

While none of the 56 near-misses over the past three years caused harm to workers or the public, the "safety pyramid" provides ample reason to

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[6] Numbering becomes cumbersome because nuclear plants can have multiple reactors, safety- and security-related events can affect one or all reactors at a plant, and some reactors experienced multiple events. Table 2 here and Table 4 later in the report attempt to clarify who had what near-miss.

reduce their occurrence. Introduced by H. W. Heinrich in his 1931 book *Industrial Accident Prevention*, the safety pyramid explains the relationship between the numbers of accidents and their severity levels.[7] As suggested by its name, the larger the base of minor accidents, the more often major accidents accidents will occur. By reducing the situations and behaviors that lead to near-misses, one reduces the number of minor accidents and serious accidents, too.

To reduce the number of near-misses, the NRC should include in its special inspection team (SIT) and augmented inspection team (AIT) processes a formal evaluation of the agency's baseline inspection effort. The baseline inspection effort covers the array of inspections conducted by the NRC at every nuclear plant in the country. When SITs and AITs report safety violations, the NRC should determine whether its baseline inspection effort could have, and should have, found the safety violations before they contributed to near-misses. The insights from the near-miss violations may enable the NRC to make adjustments in what its inspectors examine, how they examine it, and how often they examine it so as to become more likely to find violations, if they exist.

More than two decades ago, the NRC and the nuclear industry undertook parallel efforts aimed at reducing the number of scrams, or unplanned reactor shut-downs, that were occurring. Those efforts were very successful. In 1988, the average reactor experienced about 2.5 unplanned shut-downs annually (NRC 1993). By 2011, the last year data were reported, the typical reactor experienced 0.4 unplanned shut-downs annually (NRC 2012o). In other words, the typical reactor went more than two years between unplanned shut-downs.

With comparable attention to reducing the number of near-misses that are occurring, the NRC and the industry would likely achieve similar reductions. Or they can continue the status quo, hoping the plants reach the end of their operating licenses before their luck runs out.

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[7] See http://emeetingplace.com/safetyblog/2008/07/22/the-accident-pyramid/ for additional details.

Table 4: Near-Misses 2010 to 2012				
	Total Number of Near Misses	Near Misses in 2010	Near Misses in 2011	Near Misses in 2012
Number of Reactors with Near Misses	56	19	19	18
Number of Unique Reactors	40	18	14	8
Arkansas Nuclear One Unit 1	1	1		
Arkansas Nuclear One Unit 2	1	1		
Braidwood Unit 1	2	1	1	
Braidwood Unit 2	2	1	1	
Brunswick Unit 1	1	1		
Brunswick Unit 2	2	1		1
Byron Unit 1	1		1	
Byron Unit 2	2		1	1
Callaway	1		1	
Calvert Cliffs Unit 1	1	1		
Calvert Cliffs Unit 2	1	1		
Catawba Unit 1	2	1		1
Catawba Unit 2	1	1		
Cooper	1		1	
Crystal River Unit 3	1	1		
Davis-Besse	1	1		
Diablo Canyon Unit 2	1	1		
Farley Unit 1	1			1
Farley Unit 2	2	1		1
Fort Calhoun	3	1		2
Harris	1			1
HB Robinson	2	2		
Millstone Unit 2	1		1	
North Anna Unit 1	1		1	
North Anna Unit 2	1		1	
Oconee Unit 1	1		1	
Oconee Unit 2	1		1	
Oconee Unit 3	1		1	
Palisades	3		2	1
Palo Verde Unit 1	1			1
Palo Verde Unit 2	1			1
Palo Verde Unit 3	1			1
Perry	2		1	1
Pilgrim	2		2	
River Bend	1			1
San Onofre Unit 2	1			1
San Onofre Unit 3	1			1
Surry Unit 1	1	1		
Turkey Point Unit 3	1		1	
Wolf Creek	4	1	1	2

"Unique Reactors" tracks the number of reactors experiencing near-misses. For example, Brunswick Unit 2 had a near-miss in 2010 and was counted among the unique reactors that year. When it experienced another near-miss in 2012, it was not counted as a unique reactor that year.

Former NRC Chairman Says U.S. Nuclear Industry is "Going Away"

By Eliza Strickland
Posted 10 Oct 2013 | 19:25 GMT

Gregory Jaczko (http://en.wikipedia.org/wiki/Gregory_Jaczko), who was chairman of the U.S. Nuclear Regulatory Commission at the time of the Fukushima Daiichi accident (http://spectrum.ieee.org/energy/nuclear/24-hours-at-fukushima), didn't mince words in an interview with IEEE Spectrum. The United States is turning away from nuclear power, he said, and he expects the rest of the world to eventually do the same.

"I've never seen a movie that's set 200 years in the future and the planet is being powered by fission reactors—that's nobody's vision of the future," he said. "This is not a future technology. It's an old technology, and it serves a useful purpose. But that purpose is running its course."

Jaczko bases his assessment of the U.S. nuclear industry on a simple reading of the calendar. The 104 commercial nuclear reactors in the United States are aging (http://spectrum.ieee.org/energy/nuclear/fitness-tests-for-old-nuclear-reactors), and he thinks that even those nuclear power stations that have received 20 year license extensions, allowing them to operate until they're 60 years old, may not see out that term. Jaczko said the economics of nuclear reactors are increasingly difficult, as the expense of repairs and upgrades makes nuclear power less competitive than cheap natural gas. He added that Entergy's recent decision to close the Vermont Yankee plant (http://www.entergy.com/News_Room/newsrelease.aspx?NR_ID=2769) was a case in point.

"The industry is going away," he said bluntly. "Four reactors are being built, but there's absolutely no money and no desire to finance more plants than that. So in 20 or 30 years we're going to have very few nuclear power plants in this country—that's just a fact."

Jaczko spoke to IEEE Spectrum following his participation in an anti-nuclear event (https://www.facebook.com/FukushimaLessons) in New York City at which speakers discussed the lessons that could be learned from the Fukushima Daiichi accident. Speakers also included former Japanese prime minister Naoto Kan (http://en.wikipedia.org/wiki/Naoto_Kan), who headed the government during the Fukushima accident, and Ralph Nader (http://en.wikipedia.org/wiki/Ralph_nader). Several speakers talked about New York's Indian Point nuclear power station (http://www.entergy-nuclear.com/plant_information/indian_point.aspx), and Jaczko expressed his personal opinion that the plant should be shut down.

Jaczko argued that more Fukushima-type accidents are inevitable if the world continues to rely on the current types of nuclear fission reactors, and he believes that society will not accept nuclear power on that condition. "For nuclear power plants to be considered safe, they should not produce accidents like this," he said. "By 'should not' I don't mean that they have a low probability, but simply that they should not be able to produce accidents like this [at all]. That is what the public has said quite clearly. That is what we need as a new safety standard for nuclear power going forward." He acknowledged that new reactor designs such as small modular nuclear reactors (http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Small-Nuclear-Power-Reactors/#.UlbjHGRbWpY) and some Generation IV reactor (http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Generation-IV-Nuclear-Reactors/#.UlbjxmRbWpY) designs could conceivably meet such a safety standard, but he didn't sound enthusiastic.

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The New York Times

April 8, 2013

Ex-Regulator Says Reactors Are Flawed

By **MATTHEW L. WALD**

WASHINGTON — All 104 nuclear power reactors now in operation in the United States have a safety problem that cannot be fixed and they should be replaced with newer technology, the former chairman of the Nuclear Regulatory Commission said on Monday. Shutting them all down at once is not practical, he said, but he supports phasing them out rather than trying to extend their lives.

The position of the former chairman, Gregory B. Jaczko, is not unusual in that various anti-nuclear groups take the same stance. But it is highly unusual for a former head of the nuclear commission to so bluntly criticize an industry whose safety he was previously in charge of ensuring.

Asked why he did not make these points when he was chairman, Dr. Jaczko said in an interview after his remarks, “I didn’t really come to it until recently.”

“I was just thinking about the issues more, and watching as the industry and the regulators and the whole nuclear safety community continues to try to figure out how to address these very, very difficult problems,” which were made more evident by the 2011 Fukushima nuclear accident in Japan, he said. “Continuing to put Band-Aid on Band-Aid is not going to fix the problem.”

Dr. Jaczko made his remarks at the Carnegie International Nuclear Policy Conference in Washington in a session about the Fukushima accident. Dr. Jaczko said that many American reactors that had received permission from the nuclear commission to operate for 20 years beyond their initial 40-year licenses probably would not last that long. He also rejected as unfeasible changes proposed by the commission that would allow reactor owners to apply for a second 20-year extension, meaning that some reactors would run for a total of 80 years.

Dr. Jaczko cited a well-known characteristic of nuclear reactor fuel to continue to generate copious amounts of heat after a chain reaction is shut down. That “decay heat” is what led to the Fukushima meltdowns. The solution, he said, was probably smaller reactors in
could not push the temperature to the fuel’s melting point.

The nuclear industry disagreed with Dr. Jaczko’s assessment. “U.S. nuclear en
operating safely,” said Marvin S. Fertel, the president and chief executive of th

Energy Institute, the industry’s trade association. “That was the case prior to Greg Jaczko’s tenure as Nuclear Regulatory Commission chairman. It was the case during his tenure as N.R.C. chairman, as acknowledged by the N.R.C.’s special Fukushima response task force and evidenced by a multitude of safety and performance indicators. It is still the case today.”

Dr. Jaczko resigned as chairman last summer after months of conflict with his four colleagues on the commission. He often voted in the minority on various safety questions, advocated more vigorous safety improvements, and was regarded with deep suspicion by the nuclear industry. A former aide to the Senate majority leader, Harry Reid of Nevada, he was appointed at Mr. Reid’s instigation and was instrumental in slowing progress on a proposed nuclear waste dump at Yucca Mountain, about 100 miles from Las Vegas.

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Fukushima is an ongoing warning to the world on nuclear energy

The impact of nuclear disasters can last for generations. Such man-made devastation offers a lesson to all of us

Amy Goodman
theguardian.com, Thursday 16 January 2014 13.15 EST

An explosion at the Fukushima nuclear plant in Japan. Photograph: Abc Tv/EPA

"I write these facts as dispassionately as I can in the hope that they will act as a warning to the world," wrote the journalist Wilfred Burchett from Hiroshima. His story, headlined, "The Atomic Plague" appeared in the London Daily Express on 5 September 1945. Burchett violated the US military blockade of Hiroshima, and was the first

Western journalist to visit that devastated city. He wrote: "Hiroshima does not look like a bombed city. It looks as if a monster steamroller had passed over it and squashed it out of existence."

Jump ahead 66 years to 11 March 2011 and 600 miles north, to Fukushima and the Great East Japan Earthquake, which caused the tsunami. As we now know, the initial onslaught that left 19,000 people dead or missing was just the beginning. What began as a natural disaster quickly cascaded into a man-made one, as system after system failed at the Fukushima Daiichi nuclear power plant. Three of the six reactors suffered meltdowns, releasing deadly radiation into the atmosphere and the ocean.

Three years later, Japan is still reeling from the impact of the disaster. More than 340,000 people became nuclear refugees, forced to abandon their homes and their livelihoods. Filmmaker Atsushi Funahashi directed the documentary "Nuclear Nation: The Fukushima Refugees Story." In it, he follows refugees from the town of Futaba, where the Fukushima Daiichi plant is based, in the first year after the disaster. The government relocated them to an abandoned school near Tokyo, where they live in cramped, shared common areas, many families to a room, and are provided three box lunches per day. I asked Funahashi what prospects these 1,400 people had. "There's none, pretty much. The only thing the government is saying is that [for] at least six years from the accident, you cannot go back to your own town," he told me.

The refugees were given permits to return home to collect personal items, but only for two hours. Like Wilfred Burchett, Funahashi had to violate the government's ban on travel to a nuclear-devastated area in order to catch the poignant moments of one family's return on film. He explained how the family gave him one of their four permits to take the trip: "I tried to negotiate with the government, and they didn't give me any permission to go inside there. And no other independent journalist or documentary filmmakers got permission to go inside. But I got along very well with this family from Futaba," he explained, and sneaked back on their short trip.

The government's refusal to grant Funahashi access is indicative of another significant problem that has emerged since the earthquake: secrecy. Japan's conservative prime minister, Shinzo Abe, enacted a controversial state secrecy law early last December. Here in Tokyo, Sophia University Professor Koichi Nakano says of the new law, "Of course, it concerns primarily security issues and anti-terrorist measures. But ... it became increasingly clear that the interpretation of what actually constitutes state secret could be very arbitrary and rather freely defined by government leaders. For example, anti-nuclear citizen movements can come under surveillance without their knowledge, and arrests can be made."

Since the nuclear disaster, a forceful grass-roots movement has grown to permanently decommission all of Japan's nuclear power plants. The prime minister at the time of the earthquake, Naoto Kan, explained how his position on nuclear power shifted:

> My position before 11 March 2011, was that as long as we make sure that it's safely operated, nuclear power plants can be operated and should be operated. However, after experiencing the disaster of 11 March, I changed my thinking 180 degrees, completely ... there is no other accident or disaster that would affect 50 million people -- maybe a war, but there is no other accident can cause such a tragedy.

Prime Minister Abe, leading the most conservative Japanese administration since World War II, wants to restart his country's nuclear power plants, despite overwhelming public opposition. Public protests outside Abe's official residence in Tokyo continue.

"It gives you an empty feeling in the stomach to see such man-made devastation," Wilfred Burchett wrote, sitting in the rubble of Hiroshima in 1945. The two US atomic-bomb attacks on the civilian populations of Hiroshima and Nagasaki have deeply impacted Japan to this day. Likewise, the triple-edged disaster of the earthquake, tsunami and ongoing nuclear disaster will last for generations. The dangerous trajectory from nuclear weapons to nuclear power is now being challenged by a popular demand for peace and sustainability. It is a lesson for rest of the world as well.

• Denis Moynihan contributed research to this column.

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FRIDAY, JANUARY 17, 2014

Volunteers Crowdsource Radiation Monitoring to Map Potential Risk on Every Street in Japan

Safecast is a network of volunteers who came together to map radiation levels throughout Japan after the Fukushima Daiichi nuclear power plant disaster in 2011. They soon realized radiation readings varied widely, with some areas close to the disaster facing light contamination, depending on wind and geography, while others much further away showed higher readings. Safecast volunteers use Geiger counters and open-source software to measure the radiation, and then post the data online for anyone to access. Broadcasting from Tokyo, we are joined by Pieter Franken, co-founder of Safecast. "The first trip we made into Fukushima, it was an eye-opener. First of all, the radiation levels we encountered were way higher than what we had seen on television," Franken says. "We decided to focus on measuring every single street as our goal in Safecast, so for the last three years we have been doing that, and this month we are passing the 15 millionth location we have measured, and basically every street in Japan has been at least measured once, if not many, many more times."

TRANSCRIPT

This is a rush transcript. Copy may not be in its final form.

AMY GOODMAN: We're joined right now by one of the founders of a network of volunteers who came together to map radiation levels throughout Japan after the Fukushima Daiichi meltdown in 2011. They soon realized radiation readings varied widely, with some areas close to the disaster facing light contamination, depending on wind and geography, while others much further away showed higher ratings. Safecast volunteers use Geiger counters and open-source software to measure the radiation, then post the data online for anyone to access. Their effort comes as Japan recently passed a new secrecy bill.

Well, for more, we're joined by Pieter Franken, who is co-founder of Safecast.

Welcome Democracy Now! Explain what it is you've done. You're turning smartphones into Geiger counters?

PIETER FRANKEN: Not really that simple. Actually, what happened is, after the disaster happened, we were all looking for information, and we couldn't find any. And actually we tried to create a website where we could collect data and share it with people, so everybody could know what's happening. And very quickly, we found out there was almost no data. The Japanese government had published nothing, and we were basically in the dark.

After we did that, we said, We're not going to give up." We had a plan to buy lots of Geiger counters, give it to lots of people, and basically use kind of crowdsourcing to get the data and then share the data. Unfortunately, in the first 24 hours after the disaster, almost any Geiger counter on the planet was sold out, so we couldn't get all the equipment to do it.

So then we sat down and said, "How are we going to solve this problem? How do we get the data out?" Then, the idea was very simple. We decided to put a Geiger counter on a car, connected to a GPS and a computer, and start driving around and map the data—very much how Google maps streets. The whole idea was to do the same thing, but then for radiation. And that's how we started.

AMY GOODMAN: And so, take it from there.

PIETER FRANKEN: And we took it from there. And then, the first trip we made into Fukushima, it was an eye-opener. First of all, the radiation levels we encountered were way higher than what we had seen on television. On top of that, we also noticed, as you mentioned, that the radiation is not very predictable. It's not the distance to Daiichi that tells you how much radiation there is. It's very blotchy. Nearby, we measured very high and very low. Much further away, we still were measuring high levels of radiation.

So, as we were talking to people, as we were meeting people, people started to say, like, you know, "We want to have data about where we're living." And the Japanese government was basically publishing averages for cities. But people are not an average. So, people are not living in the city hall; they're living in the streets. So we decided to focus on measuring every single street as our goal in Safecast. So, for the last three years, we have been doing that. And this month, we are passing the 15 millionth location we have measured. And basically every street in Japan has been at least measured once, if not many, many more times.

AMY GOODMAN: What's the gadget you've brought in here?

PIETER FRANKEN: Yes, let me show you this. This is the system that we're currently using. We have a few hundred of these in use by our volunteers. And this is basically a Geiger counter that is in a waterproof and shock-proof case. And what happens is—the sensor is on the other side. What happens is this—

AMY GOODMAN: It's about the size of a little transistor radio.

PIETER FRANKEN: Yes. It's more or less. Yeah, it's a very small, compact device.

AMY GOODMAN: It's four inches by what? Five inches by three inches? Or—

PIETER FRANKEN: Somewhere around that, yes.

AMY GOODMAN: Yeah.

PIETER FRANKEN: And it is designed—the strap goes through the car window, and as you close the car window, the thing sits outside of the car. And basically, you have to just switch it on, and it automatically starts recording the level as you're driving around. And we designed this with lots of volunteers over the last three years, and we've been through lots of iterations, and we now are able to give these to volunteers at a much lower cost. But more importantly, it is very easy to use. You don't have to be a scientist to be able to collect this data.

AMY GOODMAN: How does the data go from the box to your company, Safecast?

PIETER FRANKEN: First of all, we're not a company. We're a volunteer organization. So, let me be clear about that.

How the data actually gets moved is very simple. It's like a camera. It has an SD card. After you're done, drive for a couple of hours, you take the SD card out, you go to our website, you upload the file, and then you can see a map of your radiation that you have measured. And then we merge that with our database, and then people can basically use an application that we—for example, on a smartphone, people can access—just a moment. They can then go to an application on an iPhone or an iPad. And I'll try to kind of zoom in to where we are right now in Tokyo. And as we're zooming in, I think you can see—

AMY GOODMAN: You're making me very nervous.

PIETER FRANKEN: You can see every single street, and you can see all the measurements we have done around that.

AMY GOODMAN: And what are the measurements, for example? I mean, Tokyo is how many miles away from Fukushima?

PIETER FRANKEN: We're about 200 kilometers away from Daiichi. As you can see on the map here, we're here in Tokyo, and this is where Fukushima is. You can see there is a big difference in color.

AMY GOODMAN: Up north, the coast.

PIETER FRANKEN: Yes.

AMY GOODMAN: It's around, what, 150 miles up the coast.

PIETER FRANKEN: Yes, yes.

AMY GOODMAN: And how toxic or radioactive is it here?

PIETER FRANKEN: Compared to the rest of Japan, Tokyo got a certain amount of fallout. Relatively speaking, I think the levels, what they are today are maybe 50 percent higher than what they were before the disaster. But compared to locations in Fukushima, it's actually relatively low. So, in terms of, you know, exposure to radioactivity, this is nothing compared to what is happening in Fukushima prefecture and the areas around there.

AMY GOODMAN: And you're taking this beyond the borders of Japan.

PIETER FRANKEN: Yes. Safecast started as a global organization. We got lots of help from outside of Japan. We would not have been able to do it without all the volunteers. And we got lots of people outside of Japan, had the same worry, and they started to worry about it, as well. And they're using the same equipment now to measure their own environments. We have people measuring—lots of people measuring in the U.S. We have people measuring in Europe. We have some volunteers now in Africa. We have just covered all the seven continents in terms of having the first measurements in, and that is spreading very quickly right now.

AMY GOODMAN: And how has the map in Japan changed? We're almost at the three-year mark, the third anniversary of Fukushima.

PIETER FRANKEN: Yes. If we look at radiation levels, specifically in Fukushima area, we see that the radiation levels have dropped by about 40 to 50 percent, depending on where and how you measure. And that is largely contributable to the half-life of some of the nucleates, and it is also contributable to the fact that the weather and the environment has specific ways of dealing with the material, and that has changed very slowly over time.

AMY GOODMAN: You're also measuring air quality.

PIETER FRANKEN: Yes, we have started to—a project to measure air quality.

AMY GOODMAN: [inaudible] radiation.

PIETER FRANKEN: Yes, we got lots of interest in the radiation project, but lots of people came to us and said, "Please, can you do something about air quality?" And initially, we were too busy solving the problem of how do we measure radiation on a large scale. And we now have started to—a project to do that.

AMY GOODMAN: On the issue of the state secrets law, how does it affect you?

PIETER FRANKEN: We believe that it should not affect us. We are actually collecting facts and data about our environment, and we strongly feel that that data should be public and open, accessible.

AMY GOODMAN: And you're saying you believe it shouldn't?

PIETER FRANKEN: It should, yes. That's our belief.

AMY GOODMAN: Are you concerned that it will?

PIETER FRANKEN: I'm personally not concerned about it, because I believe that that should not be an issue. However, how that will be reacted upon is something that we have to go and see. We don't know at this point.

AMY GOODMAN: Shouldn't the government be collecting this data and sharing it with the citizens of this country?

PIETER FRANKEN: Yes, absolutely. In the beginning of the disaster, the data that was made available by the government was almost nothing. I think through, you know, projects like Safecast, there has been lots of pressure to do more. The Japanese government has been publishing more, TEPCO has been publishing more, undoubtedly because there has been external pressure. However, the problem we have with some of the data collection is it is very selective. And the other problem is, lots of the data is available, but it is not open. So, it is copyright-protected. You can't download it and do something with it. It is restricted.

AMY GOODMAN: The Japanese government says don't trust the information you have, that it's very important to rely only on government readings.

PIETER FRANKEN: We strongly believe that in order to have credibility, you need to check your data. And we, in Safecast, our goal is to independently measure, as citizens, if the data is correct or not.

AMY GOODMAN: And the response of the corporation, TEPCO, the Tokyo Electric Power Company, that runs the, owns the nuclear power plants, to what you're doing?

PIETER FRANKEN: We have never been contacted by TEPCO, so I can't really give a good answer to that question.

AMY GOODMAN: Well, I want to thank you very much for being with us. If people want to find out more information about this Safecast Geiger counter?

PIETER FRANKEN: Yes, yes. We have a website, Safecast.org. If you go to our website, you can find more information about what we're doing, and also how you can build this device yourself and how you can participate in the Safecast project.

AMY GOODMAN: In the global mapping of radiation and air quality.

PIETER FRANKEN: Yes. Anybody anywhere can participate. It's really easy.

AMY GOODMAN: Pieter Franken, thanks so much for being with us, co-founder of Safecast.

And that does it for our three broadcasts from Tokyo, Japan. I'll be speaking Saturday, January 18th, here in Tokyo at Sophia University at 10:00 a.m. at the International Conference Room, 17th floor, No. 2 Building. Then on Sunday, the 19th of January at 7:00 p.m., I'll be speaking in Kyoto at the Kyoto Kyoiku Bunka Center. That's the Kyoto Education Culture Center. On Monday, we'll be back here in Tokyo.

That's January 20th. And I'll be speaking at the Foreign Correspondents Club of Japan, the FCCJ, for a noon talk. You can check our website at democracynow.org for all the details of these three days of talks. Then we'll be headed to the Sundance Film Festival in Park City, Utah, where we'll be broadcasting after the Martin Luther King holiday, Tuesday to Friday.

Environmental Science & Technology

Article

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Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power

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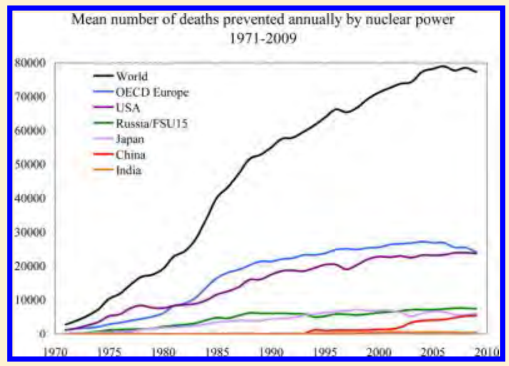
Supporting Information

ABSTRACT: In the aftermath of the March 2011 accident at Japan's Fukushima Daiichi nuclear power plant, the future contribution of nuclear power to the global energy supply has become somewhat uncertain. Because nuclear power is an abundant, low-carbon source of base-load power, it could make a large contribution to mitigation of global climate change and air pollution. Using historical production data, we calculate that global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 gigatonnes of CO_2-equivalent ($GtCO_2$-eq) greenhouse gas (GHG) emissions that would have resulted from fossil fuel burning. On the basis of global projection data that take into account the effects of the Fukushima accident, we find that nuclear power could additionally prevent an average of 420 000–7.04 million deaths and 80–240 $GtCO_2$-eq emissions due to fossil fuels by midcentury, depending on which fuel it replaces. By contrast, we assess that large-scale expansion of unconstrained natural gas use would not mitigate the climate problem and would cause far more deaths than expansion of nuclear power.



INTRODUCTION

It has become increasingly clear that impacts of unchecked anthropogenic climate change due to greenhouse gas (GHG) emissions from burning of fossil fuels could be catastrophic for both human society and natural ecosystems (in ref 1, see Figures SPM.2 and 4.4) and that the key time frame for mitigating the climate crisis is the next decade or so.[2,3] Likewise, during the past decade, outdoor air pollution due largely to fossil fuel burning is estimated to have caused over 1 million deaths annually worldwide.[4] Nuclear energy (and other low-carbon/carbon-free energy sources) could help to mitigate both of these major problems.[5]

The future of global nuclear power will depend largely on choices made by major energy-using countries in the next decade or so.[6] While most of the highly nuclear-dependent countries have affirmed their plans to continue development of nuclear power after the Fukushima accident, several have announced that they will either temporarily suspend plans for new plants or completely phase out existing plants.[2] Serious questions remain about safety, proliferation, and disposal of radioactive waste, which we have discussed in some detail elsewhere.[7]

Here, we examine the historical and potential future role of nuclear power with respect to prevention of air pollution-related mortality as well as GHG emissions on multiple spatial scales. Previous studies have quantified global-scale avoided GHG emissions due to nuclear power (e.g., refs 5 and 8–10); however, the issue of avoided human deaths remains largely unexplored. We focus on the world as a whole, OECD Europe, and the five countries with the highest annual CO_2 emissions in the last several years. In order, these top five CO_2 emitters are China, the United States, India, Russia, and Japan, accounting for 56% of global emissions from 2009 to 2011.[11] To estimate historically prevented deaths and GHG emissions, we start with data for global annual electricity generation by energy source from 1971 to 2009 (Figure 1). We then apply mortality and GHG emissions factors, defined respectively as deaths and emissions per unit electric energy generated, for relevant electricity sources (Table 1). For the projection period 2010–2050, we base our estimates on recent (post-Fukushima) nuclear power trajectories given by the UN International Atomic Energy Agency (IAEA).[6]

METHODS

Calculation of Prevented Mortality and GHG Impacts. For the historical period 1971–2009, we assume that all nuclear power supply in a given country and year would instead have been delivered by fossil fuels (specifically coal and natural gas), given their worldwide dominance and the very small contribution of nonhydro renewables to world electricity thus far (Figure 1). There are of course numerous complications involved in trying to design such a replacement scenario (e.g., evolving technological and socioeconomic conditions), and the

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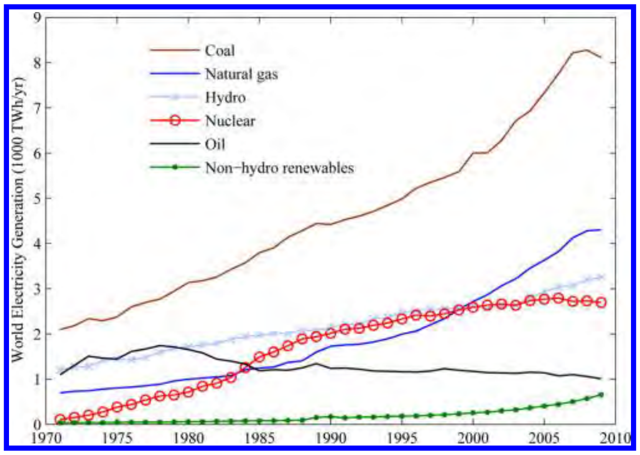

Figure 1. World electricity generation by power source for 1971−2009 (data from ref 14). In the past decade (2000−2009), nuclear power provided an average 15% of world generation; coal, gas, and oil provided 40%, 20%, and 6%, respectively; and renewables provided 16% (hydropower) and 2% (nonhydro).

Table 1. Mortality and GHG Emission Factors Used in This Study[a]

electricity source	mean value (range)	unit[b]	source
coal	28.67 (7.15−114)	deaths/TWh	ref 16
	77 (19.25−308)	deaths/TWh	ref 16 (China)[c]
	1045 (909−1182)	tCO_2-eq/GWh	ref 30
natural gas	2.821 (0.7−11.2)	deaths/TWh	ref 16
	602 (386−818)	tCO_2-eq/GWh	ref 30
nuclear	0.074 (range not given)	deaths/TWh	ref 16
	65 (10−130)[d]	tCO_2-eq/GWh	ref 34

[a]Mortality factors are based on analysis for Europe (except as indicated) and represent the sum of accidental deaths and air pollution-related effects in Table 2 of ref 16. They reflect impacts from all stages of the fuel cycle, including fuel extraction, transport, transformation, waste disposal, and electricity transport. Their ranges are 95% confidence intervals and represent deviation from the mean by a factor of ∼4. Mortality factor for coal is the mean of the factors for lignite and coal in ref 16. Mean values for emission factors are the midpoints of the ranges given in the sources. Water pollution is also a significant impact but is not factored into these values. Additional uncertainties and limitations inherent in these factors are discussed in the text. [b]TWh = terawatt hour; GWh = gigawatt hour; tCO_2-eq = tonnes of CO_2-equivalent emissions. [c]Range is not given in source for China, but for consistency with other factors, it is assumed to be 4 times lower and higher than the mean. [d]Some authors contend the upper limit is significantly higher, but their conclusions are based on dubious assumptions.[35]

retroactive energy mix cannot be known with total accuracy and realism; thus, simplifying yet tenable assumptions are necessary and justified.

To determine the proportional substitution by coal and gas in our baseline historical scenario, we first examine the world nuclear reactor properties provided by IAEA.[12] On the basis of typical international values for coal and gas capacity factors (CFs),[13] we then assume that each of the 441 reactors listed in Table 14 of ref 12 with a CF of greater than 65% is replaced by coal and each reactor with a CF of less than or equal to 65% is replaced by gas.

For each country x, we first calculate $P_i(x)$, the power (*not* energy) generated by each reactor i:

$$P_i(x) = \mathrm{CF}_i(x) \times C_i(x) \tag{1}$$

where CF_i and C_i denote the reactor capacity factor and net capacity, respectively, listed in Table 14 of ref 12. We then calculate $f_i(x)$, the CF-weighted proportion of generated power by each reactor:

$$f_i(x) = P_i(x)/\sum_i P_i(x) \tag{2}$$

Next, we calculate $F_j(x)$, the total proportion of generated nuclear power replaced by power from fossil fuel j:

$$F_j(x) = \sum_i f_i^{(j)}(x) \tag{3}$$

where $f_i^{(j)}(x)$ simply denotes grouping of all the f_i values by replacement fuel j. For reference, on the global scale, this yields about 95% replacement by coal and 5% by gas in our baseline historical scenario, which we suggest is plausible for the reasons given in the Results and Discussion section. Lastly, we calculate $I(x, t)$, the annual net prevented impacts (mortality or GHG emissions) from nuclear power in country x and year t as follows:

$$I(x, t) = \Sigma_j[\mathrm{IF}_j \times F_j(x) \times n(x, t)] - \mathrm{IF}_n \times n(x, t) \tag{4}$$

where IF_j is the impact factor for fossil fuel j (from Table 1), $n(x, t)$ is the nuclear power generation (in energy units; from refs 6 and 14), and IF_n is the impact factor for nuclear power (from Table 1). Note that the first term in eq 4 reflects gross avoided impacts, while the second reflects direct impacts of nuclear power.

For the projection period 2010−2050, using eq 4, we calculate human deaths and GHG emissions that could result if all projected nuclear power production is canceled and again replaced only by fossil fuels. Of course, some or most of this hypothetically canceled nuclear power could be replaced by power from renewables, which have generally similar impact factors as nuclear (e.g., see Figure 2 of ref 7). Thus, our results for the projection period should ultimately be viewed as upper limits on potentially prevented impacts from future nuclear power.

We project annual nuclear power production in the regions containing the top five CO_2-emitting countries and Western Europe based on the regional decadal projections in Table 4 of ref 6, which we linearly interpolate to an annual scale. To set $F_j(x)$ in eq 4, we consider two simplified cases for both the global and regional scales. In the first ("all coal"), $F_j(x)$ is fixed at 100% coal, and in the second ("all gas"), it is fixed at 100% gas. This approach yields the full range of potentially prevented impacts from future nuclear power. It is taken here because of the lack of country-specific projections in ref 6 as well as the large uncertainty in determining which fossil fuel(s) could replace *future* nuclear power, given recent trends in electricity production (Figure 1, Figure S3 [Supporting Information], and ref 14).

Methodological Limitations. The projections for nuclear power by IAEA[6] assume essentially no climate-change mitigation measures in the low-end case and aggressive mitigation measures in the high-end case. It is unclear which path the world will follow; however, these IAEA projections *do* take into account the effects of the Fukushima accident. It seems that, except possibly for Japan, the top five CO_2-emitting countries are not planning a phase-down of pre-Fukushima plans for future nuclear power. For instance, China, India, and

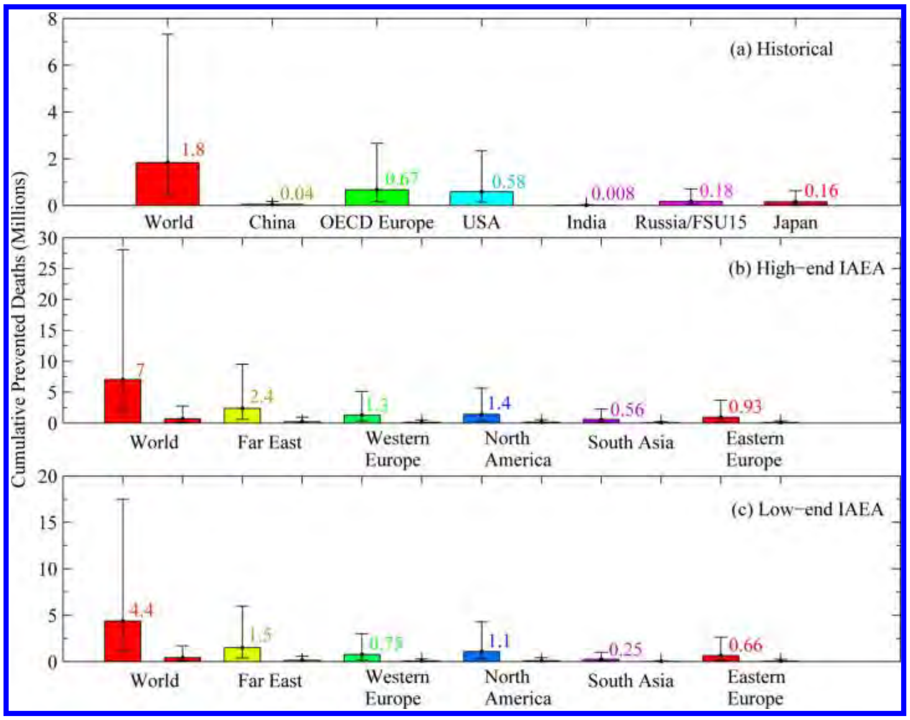

Figure 2. Cumulative net deaths prevented assuming nuclear power replaces fossil fuels. (a) Results for the historical period in this study (1971–2009), showing mean values (labeled) and ranges for the baseline historical scenario. Results for (b) the high-end and (c) low-end projections of nuclear power production by the UN IAEA[6] for the period 2010–2050. Error bars reflect the ranges for the fossil fuel mortality factors listed in Table 1. The larger columns in panels b and c reflect the all coal case and are labeled with their mean values, while the smaller columns reflect the all gas case; values for the latter are not shown because they are all simply a factor of ~10 lower (reflecting the order-of-magnitude difference between the mortality factors for coal and gas shown in Table 1). Countries/regions are arranged in descending order of CO_2 emissions in recent years. FSU15 = 15 countries of the former Soviet Union, and OECD = Organization for Economic Cooperation and Development.

Russia have affirmed plans to increase their current nuclear capacity by greater than 3-fold, greater than 12-fold, and 2-fold, respectively (see Table 12.2 of ref 2). In Japan, the future of nuclear power now seems unclear; in the fiscal year following the Fukushima accident, nuclear power generation in Japan decreased by 63%, while fossil fuel power generation increased by 26% (ref 15), thereby almost certainly increasing Japan's CO_2 emissions.

Although our analysis reflects mortality from all stages of the fuel cycle for each energy source, it excludes serious illnesses, including respiratory and cerebrovascular hospitalizations, chronic bronchitis, congestive heart failure, nonfatal cancers, and hereditary effects. For fossil fuels, such illnesses are estimated to be approximately 10 times higher than the mortality factors in Table 1, while for nuclear power, they are ~3 times higher.[16] Another important limitation is that the mortality factors exclude the impacts of anthropogenic climate change and development-related differences, as explained in the Results and Discussion section. Aspects of nuclear power that cannot meaningfully be quantified due to very large uncertainties (e.g., potential mortality from proliferation of weapons-grade material) are also not included in our analysis.

Proportions of fossil fuels in our projection cases are assumed to be fixed (for the purpose of determining upper and lower bounds) but will almost certainly vary across years and decades, as in the historical period (Figure 1). The dominance of coal in the global average electricity mix seems likely for the near future though (e.g., Figure 5.2 of ref 2). However, even if there is large-scale worldwide electric fuel switching from coal to gas, our assessment is that the ultimate GHG savings from such a transition are unlikely to be sufficient to minimize the risk of dangerous anthropogenic climate change (unless the resulting emissions are captured and stored), as discussed in the next section.

■ RESULTS AND DISCUSSION

Mortality. We calculate a mean value of 1.84 million human deaths prevented by world nuclear power production from 1971 to 2009 (see Figure 2a for full range), with an average of 76 000 prevented deaths/year from 2000 to 2009 (range 19 000–300 000). Estimates for the top five CO_2 emitters, along with full estimate ranges for all regions in our baseline historical scenario, are also shown in Figure 2a. For perspective, results for upper and lower bound scenarios are shown in Figure S1 (Supporting Information). In Germany, which has announced plans to shut down all reactors by 2022 (ref 2), we calculate that nuclear power has prevented an average of over 117 000 deaths from 1971 to 2009 (range 29 000–470 000). The large ranges stem directly from the ranges given in Table 1 for the mortality factors.

Our estimated human deaths *caused* by nuclear power from 1971 to 2009 are far lower than the avoided deaths. Globally, we calculate 4900 such deaths, or about 370 times lower than our result for avoided deaths. Regionally, we calculate approximately 1800 deaths in OECD Europe, 1500 in the United States, 540 in Japan, 460 in Russia (includes all 15 former Soviet Union countries), 40 in China, and 20 in India. About 25% of these deaths are due to occupational accidents, and about 70% are due to air pollution-related effects

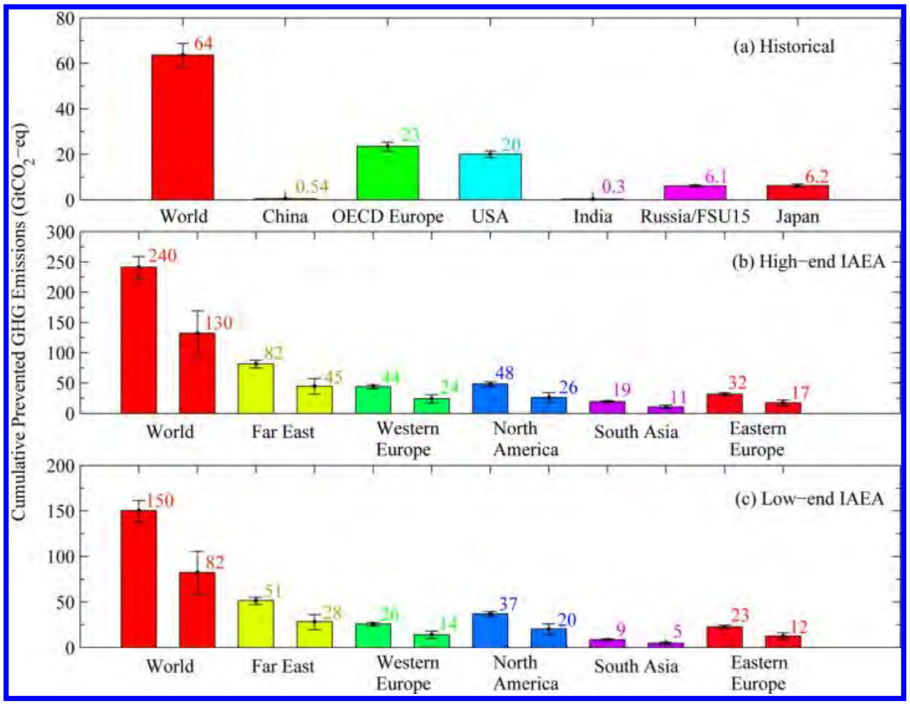

Figure 3. Cumulative net GHG emissions prevented assuming nuclear power replaces fossil fuels. Same panel arrangement as Figure 2, except mean values for all cases are labeled. Error bars reflect the ranges for the fossil fuel emission factors listed in Table 1.

(presumably fatal cancers from radiation fallout; see Table 2 of ref 16).

However, empirical evidence indicates that the April 1986 Chernobyl accident was the world's only source of fatalities from nuclear power plant radiation fallout. According to the latest assessment by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR),[17] 43 deaths are conclusively attributable to radiation from Chernobyl as of 2006 (28 were plant staff/first responders and 15 were from the 6000 diagnosed cases of thyroid cancer). UNSCEAR[17] also states that reports of an increase in leukemia among recovery workers who received higher doses are inconclusive, although cataract development was clinically significant in that group; otherwise, for these workers as well as the general population, "there has been no persuasive evidence of any other health effect" attributable to radiation exposure.[17]

Furthermore, no deaths have been conclusively attributed (in a scientifically valid manner) to radiation from the other two major accidents, namely, Three Mile Island in March 1979, for which a 20 year comprehensive scientific health assessment was done,[18] and the March 2011 Fukushima Daiichi accident. While it is too soon to meaningfully assess the health impacts of the latter accident, one early analysis[19] indicates that annual radiation doses in nearby areas were much lower than the generally accepted 100 mSv threshold[17] for fatal disease development. In any case, our calculated value for global deaths caused by historical nuclear power (4900) could be a major overestimate relative to the empirical value (by 2 orders of magnitude). The absence of evidence of large mortality from past nuclear accidents is consistent with recent findings[20,21] that the "linear no-threshold" model used to derive the nuclear mortality factor in Table 1 (see ref 22) might not be valid for the relatively low radiation doses that the public was exposed to from nuclear power plant accidents.

For the projection period 2010−2050, we find that, in the all coal case (see the Methods section), an average of 4.39 million and 7.04 million deaths are prevented globally by nuclear power production for the low-end and high-end projections of IAEA,[6] respectively. In the all gas case, an average of 420 000 and 680 000 deaths are prevented globally (see Figure 2b,c for full ranges). Regional results are also shown in Figure 2b,c. The Far East and North America have particularly high values, given that they are projected to be the biggest nuclear power producers (Figure S2, Supporting Information). As in the historical period, calculated deaths caused by nuclear power in our projection cases are far lower (2 orders of magnitude) than the avoided deaths, even taking the nuclear mortality factor in Table 1 at face value (despite the discrepancy with empirical data discussed above for the historical period).

The substantially lower deaths in the projected all gas case follow simply from the fact that gas is estimated to have a mortality factor an order of magnitude lower than coal (Table 1). However, this does not necessarily provide a valid argument for such large-scale "fuel switching" for mitigation of either climate change or air pollution, for several reasons. First, it is important to bear in mind that our results for prevented mortality are likely conservative, because the mortality factors in Table 1 do not incorporate impacts of ongoing or future anthropogenic climate change.[16] These impacts are likely to become devastating for both human health and ecosystems if recent global GHG emission trends continue.[1,3] Also, potential global natural gas resources are enormous; published estimates for technically recoverable unconventional gas resources suggest a carbon content ranging from greater than 700 $GtCO_2$ (based on refs 23 and 24) to greater than 17 000 $GtCO_2$ (based on refs 24 and 25). While we acknowledge that natural gas might play an important role as a "transition" fuel to a clean-energy era due to its lower mortality (and emission) factor relative to coal, we stress that long-term, widespread use

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of natural gas (without accompanying carbon capture and storage) could lead to unabated GHG emissions for many decades, given the typically multidecadal lifetime of energy infrastructure, thereby greatly complicating climate change mitigation efforts.

GHG Emissions. We calculate that world nuclear power generation prevented an average of 64 gigatonnes of CO_2-equivalent ($GtCO_2$-eq), or 17 GtC-eq, cumulative emissions from 1971 to 2009 (Figure 3a; see full range therein), with an average of 2.6 $GtCO_2$-eq/year prevented annual emissions from 2000 to 2009 (range 2.4−2.8 $GtCO_2$/year). Regional results are also shown in Figure 3a. Our global results are 7−14% lower than previous estimates[8,9] that, among other differences, assumed all historical nuclear power would have been replaced only by coal, and 34% higher than in another study[10] in which the methodology is not explained clearly enough to infer the basis for the differences. Given that cumulative and annual global fossil fuel CO_2 emissions during the above periods were 840 $GtCO_2$ and 27 $GtCO_2$/year, respectively,[11] our mean estimate for cumulative prevented emissions may not appear substantial; however, it is instructive to look at other quantitative comparisons.

For instance, 64 $GtCO_2$-eq amounts to the cumulative CO_2 emissions from coal burning over approximately the past 35 years in the United States, 17 years in China, or 7 years in the top five CO_2 emitters.[11] Also, since a 500 MW coal-fired power plant typically emits 3 $MtCO_2$/year,[26] 64 $GtCO_2$-eq is equivalent to the cumulative lifetime emissions from almost 430 such plants, assuming an average plant lifetime of 50 years. It is therefore evident that, without global nuclear power generation in recent decades, near-term mitigation of anthropogenic climate change would pose a much greater challenge.

For the projection period 2010−2050, in the all coal case, an average of 150 and 240 $GtCO_2$-eq cumulative global emissions are prevented by nuclear power for the low-end and high-end projections of IAEA,[6] respectively. In the all gas case, an average of 80 and 130 $GtCO_2$-eq emissions are prevented (see Figure 3b,c for full ranges). Regional results are also shown in Figure 3b,c. These results also differ substantially from previous studies,[9,10] largely due to differences in nuclear power projections (see the Supporting Information).

To put our calculated overall mean estimate (80−240 $GtCO_2$-eq) of potentially prevented future emissions in perspective, note that, to achieve a 350 ppm CO_2 target near the end of this century, cumulative "allowable" fossil CO_2 emissions from 2012 to 2050 are at most ~500 $GtCO_2$ (ref 3). Thus, projected nuclear power could reduce the climate-change mitigation burden by 16−48% over the next few decades (derived by dividing 80 and 240 by 500).

Uncertainties. Our results contain various uncertainties, primarily stemming from our impact factors (Table 1) and our assumed replacement scenarios for nuclear power. In reality, the impact factors are not likely to remain static, as we (implicitly) assumed; for instance, emission factors depend heavily on the particular mix of energy sources. Because our impact factors neglect ongoing or projected climate impacts as well as the significant disparity in pollution between developed and developing countries,[16] our results for both avoided GHG emissions and avoided mortality could be substantial underestimates. For example, in China, where coal burning accounts for over 75% of electricity generation in recent decades (ref 14; Figure S3, Supporting Information), some coal-fired power plants that meet domestic environmental standards have a mortality factor almost 3 times higher than the mean global value (Table 1). These differences related to development status will become increasingly important as fossil fuel use and GHG emissions of developing countries continue to outpace those of developed countries.[11]

On the other hand, if coal would not have been as dominant a replacement for nuclear as assumed in our baseline historical scenario, then our avoided historical impacts could be overestimates, since coal causes much larger impacts than gas (Table 1). However, there are several reasons this is unlikely. Key characteristics of coal plants (e.g., plant capacity, capacity factor, and total production costs) are historically much more similar to nuclear plants than are those of natural gas plants.[13] Also, the vast majority of existing nuclear plants were built before 1990, but advanced gas plants that would be suitable replacements for base-load nuclear plants (i.e., combined-cycle gas turbines) have only become available since the early 1990s.[13] Furthermore, coal resources are highly abundant and widespread,[24,25] and coal fuel and total production costs have long been relatively low, unlike historically available gas resources and production costs.[13] Thus, it is not surprising that coal has been by far the dominant source of global electricity thus far (Figure 1). We therefore assess that our baseline historical replacement scenario is plausible and that it is not as significant an uncertainty source as the impact factors; that is, our avoided historical impacts are more likely underestimates, as discussed in the above paragraph.

Implications. More broadly, our results underscore the importance of avoiding a false and counterproductive dichotomy between reducing air pollution and stabilizing the climate, as elaborated by others.[27−29] If near-term air pollution abatement trumps the goal of long-term climate protection, governments might decide to carry out future electric fuel switching in even more climate-impacting ways than we have examined here. For instance, they might start large-scale production and use of gas derived from coal ("syngas"), as coal is by far the most abundant of the three conventional fossil fuels.[24,25] While this could reduce the very high pollution-related deaths from coal power (Figure 2), the GHG emissions factor for syngas is substantially higher (between ~5% and 90%) than for coal,[30] thereby entailing even higher electricity sector GHG emissions in the long term.

In conclusion, it is clear that nuclear power has provided a large contribution to the reduction of global mortality and GHG emissions due to fossil fuel use. If the role of nuclear power significantly declines in the next few decades, the International Energy Agency asserts that achieving a target atmospheric GHG level of 450 ppm CO_2-eq would require "heroic achievements in the deployment of emerging low-carbon technologies, which have yet to be proven. Countries that rely heavily on nuclear power would find it particularly challenging and significantly more costly to meet their targeted levels of emissions."[2] Our analysis herein and a prior one[7] strongly support this conclusion. Indeed, on the basis of combined evidence from paleoclimate data, observed ongoing climate impacts, and the measured planetary energy imbalance, it appears increasingly clear that the commonly discussed targets of 450 ppm and 2 °C global temperature rise (above preindustrial levels) are insufficient to avoid devastating climate impacts; we have suggested elsewhere that more appropriate targets are less than 350 ppm and 1 °C (refs 3 and 31−33). Aiming for these targets emphasizes the importance of retaining and expanding the role of nuclear power, as well as energy efficiency improvements and renewables, in the near-term global energy supply.

■ ASSOCIATED CONTENT

Supporting Information

Comparison with avoided GHG emissions in projection periods of prior studies; figures showing upper and lower bounds for prevented deaths and GHG emissions assuming nuclear power replaces fossil fuels from 1971–2009, projections of nuclear power production by region, and total electricity production from 1971–2009 by fuel source for the top five CO_2-emitting countries and OECD Europe. This material is available free of charge via the Internet at http://pubs.acs.org.

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Author Contributions

P.K. designed the study with input from J.H.; P.K. performed the calculations and analysis and wrote the paper with feedback from J.H.

Notes

The authors declare no competing financial interest.

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