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Nuclear fear: The irrational obstacle to real climate action

Kerry Emanuel

ABSTRACT
History instructs us that electrical power can be decarbonized in less than a dozen years with combinations of renewable and nuclear energy, but exaggerated fears of the latter have made it too costly and unpopular to develop and deploy in much of the world, allowing Russia and China to capture the nuclear export market. If humanity is genuinely serious about rapid decarbonization to avoid the worst health and climate risks, it will need to take steps to rapidly improve and deploy both nuclear and renewable energy.

KEYWORDS
Nuclear power; climate change; nuclear safety; comparative risk; risk assessment

Twenty-three minutes into a 41-minute flight from Houston to Dallas, Texas, on September 29, 1959, a turboprop engine on the left-hand side of a new Lockheed Electra began to whirl around on its axis, tearing the wing off the aircraft. All onboard were killed. A subsequent investigation established that the powerful engines were subject to a resonant oscillation known as a "whirl mode" and the Electra was re-designed to eliminate it. The new Electra was so strong that it was used in atmospheric research to fly into dangerous windstorms, including hurricanes, but it never regained the confidence of the public and production ceased well before Lockheed had recovered its costs.

Since 1970, deaths per trillion passenger-miles flown have declined from about 3,200 to 40, an 80-fold decrease attributable mostly to improved aircraft technology and air and ground traffic control. Per passenger-mile, flying today carries one-sixtieth the danger of driving and is roughly one-tenth of one percent as dangerous as riding a bicycle. Still, planes occasionally crash, and there are those whose fear of flying leads them to take much more dangerous forms of transportation.

No doubt, airplanes could be made still safer. For example, airframes could be made even stronger, more redundant systems could be installed, and the flight crew could be increased, but these changes of course would come at a cost. Suppose, for example, that air travel could be made twice as safe at the cost of paying twice as much for a ticket. In that case, many potential air passengers would switch to other forms of transportation, and because those modes are far less safe, net fatalities would increase. We might say then that air travel had been made too safe.

By this logic, nuclear energy is absurdly too safe. Almost all fatalities in the history of nuclear power plants resulted from a single accident: the 1986 meltdown of the number 4 reactor at the Chernobyl nuclear power plant in what was then the Soviet Union. It is generally agreed that 60 people died as a direct result of the radiation released in the accident. But there is wide disagreement on the long-term effects of comparatively minor doses of radiation, with estimates ranging from a few thousand to as many as 60,000, if one assumes that deaths per unit exposure to radiation rise linearly with exposure. The World Health Organization's official estimate is 4,000.

According to new peer-reviewed research in *Environmental Research*,[1] an estimated 8.7 million people die prematurely every year of respiratory diseases resulting from inhalation of particulates from fossil fuel combustion. Accepting the extreme upper limit of 60,000 fatalities from Chernobyl, this means that more people die from fossil fuels every three days than have died in the whole history of nuclear power. Had global nuclear power expanded from 1990 to 2010 at the rate it did from 1970 to 1990, we would have been spared the approximately 32 million lives lost over that period as a consequence of fossil fuel combustion.

Among other deficiencies, the Chernobyl plant had no containment structure, a safety measure that would have prevented such widespread dispersal of radioactive material. As with the Electra, engineers learned a great deal from the accident and no power stations of Chernobyl's design were ever built again; likewise, measures were taken to ensure that the five remaining Russian plants of similar design would not suffer

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a similar fate.[2] Unlike the case of the Electra, though, the public turned not just against old Soviet reactor designs but the whole concept of nuclear power.

Fear and the decline of nuclear power

Why, then, do people tolerate aircraft accidents but not nuclear ones? Why did we trade one of the safest forms of energy production ever created for the most dangerous? It is as though a single high-profile airplane crash and a few non-fatal crash landings had led to the cessation of commercial aviation in favor of very high-speed automobiles.

Fear was one of several factors that crippled nuclear power in the West. In the United States and elsewhere, orders for new nuclear plants skyrocketed in the early 1970s, but as it became apparent that projections of increased energy demand were too large, orders began to fall off. Then in 1979, a reactor at the Three Mile Island nuclear power plant in Pennsylvania suffered a partial meltdown. This remains the most serious nuclear power accident in the United States, but there were no fatalities, actual or projected. Nonetheless, the accident itself and subsequent anti-nuclear campaigns turned the tide of public sentiment against nuclear power, and no new reactors were constructed in the United States between the time of the accident and 2012. Regulations were tightened up, and the lack of demand led to the desiccation of manufacturing supply chains and the training and influx of highly skilled talent needed to run nuclear power plants.

Lacking incentive, nuclear innovation dried up as well, largely preventing the large increases in efficiency and safety experienced by healthy, technology-intensive enterprises such as aviation. By the time demand for carbon-free energy started to increase in the 2000s, the start-up costs of a new nuclear power plant were too large to compete with natural gas and subsidized renewables. (Until very recently, nuclear power was not considered "green" and was not eligible for subsidies enjoyed by renewables even though it has comparably low carbon emissions.) Even so, nuclear power has provided about 20 percent of US electricity since the late 1980s and remains the largest single source of carbon-free energy.

In Western Europe, France, Sweden, Belgium, and Switzerland invested heavily in nuclear power and ramped it up very fast in response to the 1973 oil crisis. Without any native fossil fuel resources, these nations were strongly motivated to become less dependent on foreign oil and gas. Today, nuclear provides about 70 percent of France's electricity, with hydro filling in most of the rest, and France has among the lowest consumer electricity prices in Europe.

At its 2005 peak, nuclear power supplied about 11 percent of electrical power in Germany, but that percentage fell off rapidly, especially after the 2011 Japanese Fukushima Daiichi nuclear accident that followed a deadly tsunami. (That tsunami killed about 16,000 people in Japan, many of whom died as a result of infrastructure failures, including gas explosions. There were, at most, a few radiation-related deaths from the Fukushima accident, yet the earthquake and tsunami are today often remembered in relation to Fukushima.) Under Chancellor Angela Merkel, and bowing to post-Fukushima pressure from Germany's strong Green Party, Germany adopted a policy that aimed to phase out nuclear power and replace it mostly with renewables. To a large extent, that has been accomplished, but today as much electricity is generated by fossil fuels as by renewables, and annual premature deaths in Germany from air pollution remain around 65,000. By shuttering its nuclear power plants, Germany lost an opportunity to appreciably reduce this number. Germany, like many other nations, is not currently on track to meet its carbon emission reduction obligations under the Paris Climate Agreement of 2015.

Sensible options for dealing with climate change

It has been known for at least a half century that Earth's climate is regulated by trace amounts of long-lived greenhouse gases, and it is hardly surprising that doubling or tripling carbon dioxide content will have large effects on climate. The accelerating, anthropogenic increase in carbon dioxide concentrations from 280 parts per million in the pre-industrial era to over 400 parts per million today is unequivocal, as is the response of the global mean temperature. While the precise trajectories of hazards such as droughts, floods, wildfires, and hurricanes continue to be researched, there is no longer any question that the countries of the world run serious risks if they continue to rely on fossil fuels for energy and that they should take sensible measures to mitigate these risks.

What constitutes sensible measures? Broadly, they fall into two groups: reductions of fossil fuel consumption and extraction, and storage of carbon dioxide from the exhaust streams of fossil fuel use or from the atmosphere. At this point in history, any sensible measures must rely on technology that has already been developed and not on wishful thinking about new technology, and those measures must not cost more than the risk reduction warrants. This is not to suggest that research and development of new carbon-free energy sources, storage technology, and means of extracting and sequestering carbon should not be very well funded – they should be. But the world can no longer afford to wait for technological miracles.

So, what are sensible options? Methods of capturing and sequestering carbon exist, but they are too expensive right now to implement at the scale needed to solve the problem. This turns the focus to carbon-free energy. Here, it is vital to recognize two essential facts: First, electricity accounts for only about 25 percent of global power consumption, and the world must also decarbonize transportation, industrial processes, heating of homes and commercial buildings, and agriculture. Second, civilization must not only decarbonize existing energy production but account for large increases in energy demand projected to come from developing nations. Attempting to appreciably curtail that demand is likely to be counterproductive because energy is key to alleviating poverty and, thereby, reducing large growth in population that is itself an important driver of increasing energy demand and carbon emissions. The net challenge is daunting indeed.

At present, there are only four major virtually carbon-free energy sources: solar, wind, hydro, and nuclear fission.

Hydropower is already largely built out; there are not many opportunities left for building new dams. Moreover, in some places, hydropower is being compromised by drought brought about by climate change.

Almost all the emphasis today is on the rapid deployment of solar and wind energy technology. The capital costs of solar panels and wind turbines have dropped steeply in recent decades and are no longer viewed as an impediment to future growth of these renewables. But there is a major obstacle to expanding solar and wind beyond roughly 40 percent of most power grids: Without appreciable dispatchable energy on these grids, it becomes necessary to store energy generated from highly intermittent sunlight and wind. At the moment, the costs of battery and pumped water storage are far too high to make 100 percent renewables, plus storage, a viable option. Another obstacle to scaling up wind and solar power is their large real-estate requirements. Solar farms take up around 300 times more land than a conventional gas or nuclear power plant.

I am writing this essay in a small fishing village in Maine, where there is widespread opposition to a proposed offshore wind farm because it would seriously limit available territory for fishing (not just to support the turbines themselves but the undersea power cables that connect them to each other and to the mainland) and they would pose a navigational hazard. Local opposition to wind in particular is fairly common. Through a concerted effort, Germany managed to increase to 45 percent its percentage of electricity production by renewables, but it has the highest consumer electricity prices in Western Europe and relies on surrounding nations to supply power in times of low local production. Moreover, there are still large emissions from non-electrical power consumption, including transportation and industry.

A compelling combination: renewables and nuclear power

As of this writing, it is clear that the fastest routes to complete decarbonization of electrical power production involve judicious combinations of renewables and nuclear fission. This is more an empirical than a theoretical statement; Sweden and France did exactly this and did so in a dozen years or so. A nuclear renaissance coupled with accelerated development and deployment of solar and wind would immediately save lives by displacing fossil fuels and would put the world on a faster track to shutting down carbon emissions. Greatly accelerating the current rate of carbon-free energy deployment can also provide enough clean energy to accelerate the electrification of vehicles. (By "electrification," I include here not just battery storage but also hydrogen-based fuels that are manufactured using electricity.) Certain types of advanced nuclear reactors can also provide the high-temperature heat that some industrial activities require. By addressing the energy needs of transportation, industry, and commercial and residential heating, the combined nuclear-renewable pathway can reduce the carbon footprints of most of the current sources of energy consumption.

In contemplating the extraordinary transition away from fossil fuels that is needed to mitigate serious climate risk, one must account for the risks associated with carbon-free energy. Risks associated with nuclear power include uranium mining, reactor safety, nuclear waste, and nuclear proliferation. We have already argued that current reactor designs are "too safe," in the sense that their high costs are prolonging dependence on far more lethal fossil fuels. The answer is not to make reactors less safe[3] but to transition to new designs that are inherently passively safe. Likewise, nuclear waste can be safely deposited deep in geologically stable bedrock, as is being done in Finland, for example. Neither plant safety nor waste disposal is considered a serious risk by most energy experts, especially when weighed against the alternatives.

Uranium mining does cause excess deaths from lung cancer and other diseases related to radon exposure; the US National Institute for Occupational Safety and Health estimates that over a 50-year period there were about 600 deaths (excess over background) attributable to uranium mining. This can be compared to estimates by the same organization of about 1,600 deaths in a single year (2018) from black lung disease resulting from coal mining in the United States.

Probably the most serious risks of nuclear power involve nuclear proliferation. There are two aspects of present-day reactor technology that are susceptible to exploitation by dangerous nations and terrorists: the enrichment of uranium 235 levels needed for fuel used in uranium-based reactors, and the production of plutonium as a waste product of such reactors.

To be used in a power reactor, uranium must be enriched so three to five percent of it consists of the uranium 235 isotope,[4] whereas nuclear weapons require enrichment to about 90 percent. Thus, enriched uranium stolen from a power reactor cannot be used directly to manufacture a weapon, but it would save steps in an enrichment process. A popular means of enriching makes use of cascades of gas centrifuges, with each level providing additional enrichment. Organizations that enrich fuel for peaceful power reactors can rather easily add more levels of centrifuges to produce weapons-grade highly enriched uranium. But such organizations may find it easier simply to build even larger centrifuge stacks to enrich uranium so it contains 90 percent of the uranium 235 isotope.

This is essentially what has happened in the two nations whose real or potential production of nuclear weapons is currently a source of concern: Iran and North Korea. Neither country started with operating commercial nuclear power reactors, and North Korea has yet to build a commercial nuclear power plant (although it has operated reactors of other types since the 1980s). Iran opened its first and so far only commercial nuclear power plant in 2011, long after it started its nuclear weapons efforts. This illustrates that organizations can pursue nuclear weapons without first building nuclear power reactors and that the nuclear weapons programs of the two nation-states of most concern today did not benefit much from commercial nuclear power plants.

Another concern is the production of plutonium that is a by-product of uranium-based power reactors. The reprocessing of used nuclear fuel separates plutonium from other waste products, and once separated, it can be used directly in the manufacture of nuclear weapons. For this reason, plutonium is guarded as though it were itself a nuclear weapon.

Some of the risks of conventional uranium reactors could be mitigated by using breeder reactors based on thorium-232, a fertile (not fissile) material that is somewhat more abundant than uranium. When bombarded by neutrons, U-233 is produced and serves as the reactor fuel. As with U-235, U-233 can be enriched to weapons-grade. However, the by-products of reactors using U-233 are somewhat less dangerous; in particular, the amount of plutonium produced is only about 2 percent of that from a comparable U-235 reactor and it has an isotopic form that makes it difficult to use for weapons. Moreover, there is no radiation danger from mining thorium, and the half-life of the nuclear waste produced is a few hundred years rather than the tens of thousands of years from conventional reactors. Yet thorium reactors are far from commercialization, and it remains unclear whether they will prove economically viable.

While the risks of nuclear power are very real, they must be weighed carefully against the alternatives. Even solar photovoltaics present environmental risks, mostly from the chemicals used in the manufacture of solar panels or contained in the panels themselves. These latter include highly toxic materials such as gallium arsenide, copper-indium-gallium-diselenide, and cadmium, which pose significant environmental and health risks. While these chemicals can be removed from used solar panels, it is not currently economically feasible to do this at scale. Coupled with large land-use requirements and associated habitat reduction, it is far from clear whether solar is less risky than nuclear, in an overall environmental sense.

What is crystal clear is that nuclear and renewables are far, far safer than fossil fuels, even before climate risk is considered. Rapid expansion of renewables and nuclear would no doubt lead to innovations that would drive down capital and operating costs and improve safety, as happened with commercial aviation. In the case of nuclear power, a nuclear renaissance would likely reduce the capital costs of new construction and further improve the safety of reactors, fuel supply chains, and waste disposal, and lead to other innovations such as improved efficiency. Small modular reactors are one way to reduce start-up costs and would be a step toward more local community control of power sources.

In weighing whether to incentivize new nuclear developments alongside renewables, one must consider the current expansion of nuclear power in China and Russia. China currently operates 49 nuclear power plants, with 16 under construction and 39 more in the planning stages. Fifty new nuclear power plants are under construction worldwide. China, Russia, and South Korea are among nations that build nuclear reactors for their export markets, selling to nations as diverse as India, Argentina, the United Arab Emirates, and Egypt. Owing to efficiencies in manufacture, South Korean reactors are particularly cost effective, with capital costs about one third of those of comparable size reactors in the United States and Europe. Unsurprisingly, the nations that are building new reactors for domestic use and for export are also ahead in deploying innovative designs. China is currently building a high-temperature gas reactor and a small modular reactor.

As pressure continues to mount to decarbonize energy production, many nations are choosing pathways that involve various combinations of nuclear and renewable energy, combinations that were highly successful in eliminating carbon-based electricity in the past. For those who remain skeptical of nuclear power, the real-world choice may lie not in whether nuclear is part of a future energy portfolio, but rather whose nuclear power technology is brought to bear. Global competition to innovate and produce nuclear and renewable energy in combination, accompanied by suitable government-based incentives, provides the most plausible, highest-paced pathway to transition our economy away from the fossil fuel-based past into a clean, efficient, and economical carbon-free future.

Notes

1. https://www.sciencedirect.com/science/article/abs/pii/S0013935121000487
2. These measures do not bring these reactors up to modern safety standards, and for this reason, they probably ought to be shut down.
3. The US Nuclear Regulatory Commission demands that nuclear power plants be able to withstand events whose annual likelihood is one in 10 million. This is an absurd standard by any measure, given that it is impossible to accurately quantify the probable magnitude of events that would occur on average once in 10 million years. See Regulatory Guide 1.221, Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants. (nrc.gov) (https://www.nrc.gov/docs/ML1109/ML110940300.pdf).
4. See https://www.energy.gov/ne/nuclear-fuel-facts-uranium.

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Kerry Emanuel is a prominent meteorologist and climate scientist at MIT, who specializes in moist convection in the atmosphere, and tropical cyclones. He is co-founder of the MIT Lorenz Center, a climate think tank which fosters creative approaches to learning how climate works. Professor Emanuel is the author or co-author of over 200 peer-reviewed scientific papers and three books.