Climate Change is Worse Than You Think and the Solution is Not What You Think

Thomas L. Carson

What Will be Required in Order to Avert Calamity

There are clear and ominous signs that climate change is already beginning to have extremely bad consequences. Many people say that we need to reduce our emissions of greenhouse gases during the coming decade(s), but that won't be nearly enough. Not only do we need to greatly reduce and end our current emissions during the next few decades, we need to do something that will be much more difficult: we need to greatly reduce overall levels of greenhouse gases in the atmosphere. The task before us is much greater than most people realize and the means to avoid a climate catastrophe that are most widely proposed are based on wishful thinking about the present state of solar and battery technology and unreasonable, disproportionate fears of nuclear power.

The warming of the earth is caused by all of the greenhouse gases present in the atmosphere at any given time, not just by current emissions. Until the 1800s, carbon dioxide levels were about 280 parts per million, a number that was more or less constant during the preceding 800,000 years (Climate.gov). As of May 2021, CO_2 levels in the atmosphere had reached 419 parts per million (NOAA Research News), almost one third more than they were before the industrial revolution. The level of greenhouse gases in the earth's atmosphere is growing *very* rapidly. Fully half of the additional carbon that has accumulated in the atmosphere since the industrial revolution was emitted during the last thirty years, and 85% of the additional carbon was added since 1945 (Wallace-Wells, 4). Even if we make large reductions in current emissions, such as those mandated by the 2016 Paris Climate Accords and the 2021 climate summit in Scotland, overall levels of greenhouse gases will remain at elevated levels for a very long time and continue to drive the further warming of the earth.

Atmospheric CO_2 levels are rising very rapidly and alarmingly. However, there are also natural "carbon sinks" that remove it from the atmosphere. At the present time, roughly half of the new CO_2 created by burning fossil fuels remains in the atmosphere, 25% is absorbed by plants and trees, and 25% is absorbed by the oceans (NOAA, 2015). It is unclear that the oceans can continue to absorb so much CO_2 indefinitely. Another very harmful consequence of CO_2 emissions is that the oceans are becoming much more acidic, which causes great harm to marine life and fisheries. Wildfires and the disappearance of tropical rainforests are rapidly reducing the extent to which plants absorb CO_2. There is potential to improve this situation through reforestation. However, there isn't nearly enough available land for us to absorb current emissions by planting more trees:

> You'd need somewhere around 50 acres' worth of trees, planted in tropical areas to absorb the emissions produced by an average American in her lifetime. Multiply that by the population of the United States, and you get more than 16 billion acres, or 25 million square miles, roughly half the landmass of the world. Those trees would have to be maintained forever. And that's just for the United States [At present, the US accounts for only 15% of global emissions (Union of Concerned Scientists)]... there's no practical way to plant enough [trees]... to deal with the problems caused by burning fossil fuels (Gates, 129).

The existence of carbon sinks and uncertainty about how much CO_2 they can absorb in the future, makes it difficult to determine how much greenhouse gas humans can emit in the future without continuing to raise overall concentrations of greenhouse gases in the earth's atmosphere. But, in any case, it will not be sufficient for us to keep greenhouse gases at their current very elevated levels. We need to reduce them back to near the levels that prevailed before the current warming began. Very drastic cuts in emissions will be necessary, but not sufficient, in order to achieve that goal, because CO_2 and other greenhouse gases present in the atmosphere are likely to remain there for centuries. According to the MIT meteorologist Keri Emanuel, it will take "thousands of years for CO_2 levels to return to normal [TLC - pre-industrial levels] once emissions cease" (Emanuel, 51). If that is correct, then even if humans ceased all emissions of greenhouse gases tomorrow, global temperatures would remain at elevated levels for *many centuries* and polar ice would continue to melt and sea levels would continue to rise.

There are additional reasons for alarm and additional reasons to think that we need to remove very large amounts of greenhouse gases from the atmosphere. The melting of ice and snow creates a feedback loop that increases global warming. Ice and snow radiate solar energy back into outer space. As ice and snow recede, more solar energy is absorbed by the earth. This warms the earth which melts more ice and snow, and so on. The warming of polar regions is beginning to cause the release of methane from the arctic permafrost. Since methane is a very potent greenhouse gas (many times more potent than CO_2), this will heat the earth which will cause more methane to be released, and so on. Both of these feedback loops are now operating and contributing to global warming. These and other vicious feedback loops have the potential to become much worse in the future. Other very harmful feed back loops include the following: 1. The warming of the oceans and lakes causes greater evaporation which causes there to be more water vapor in the atmosphere. Since water vapor is a greenhouse gas (American Chemical Society), this causes the earth to retain more solar heat which causes there to be more evaporation and so on. 2. Very large amounts of frozen methane and frozen CO_2 are contained in ice crystals on the ocean floor. Huge amounts of methane and CO_2 might be released if the oceans warm enough to destabilize those crystals (Woody and Gates, 176). "The ocean is warming as carbon emissions continue to rise, and scientists say the temperature of the seawater surrounding some hydrate caps is within a few degrees of dissolving them" (Woody). Large amounts of methane are already seeping into the atmosphere from thousands of hydrothermal vents in shallow coastal ocean waters (Woody).

Per-capita yearly US emissions of CO_2 (14.4 tons) are very high - they are the 11^{th} highest in the world. Our emissions rate is nearly as high as that of Canada, the world's worst per-capita emitter among industrial nations (Union of Concerned Scientists), and it is more than twice China's per-capita yearly emissions of 7.064 tons (Saving Nature). But, at present, the US creates just 14% of total global CO_2 emissions (Union of Concerned Scientists). So, it won't be nearly enough for the US to reduce or end its own emissions. We need to create *enforceable* international agreements to end emissions of greenhouse gases. The Paris Climate Accords and the agreements reached at the 2021 climate summit in Scotland include no enforcement mechanisms.

The 2021 climate agreements include some very desirable provisions. They call for the world to eliminate the burning of coal, drastically reduce methane emissions, and provide considerable economic aid for poor nations to develop carbon-free energy. The agreements aim at reaching net zero greenhouse gas emissions by 2050. But China, the world's largest emitter of greenhouse gases, and India, another large and growing emitter, were not represented at the meeting and are not parties to the agreement. Even if all of the parties to the agreement do what they have pledged to do, global temperatures will probably rise by 2.4º C, not 1.5º C (BBC, November 2021). Further, it seems unlikely that these pledges will all be met, since the agreements are purely voluntary and don't include any means to compel nations to do what they have promised to do. We need to create *enforceable* climate agreements. Additionally, in the not too distant future, the global community will need to start removing enormous amounts of greenhouse cases from the atmosphere.

Why We Can't Rely on Wind and Solar Power Alone

Recently, there have been dramatic improvements in wind and solar technology. But, for the foreseeable future, it will be impossible to rely on wind and solar power alone for electrical generation. Solar panels can't generate electricity at night and the winds don't always blow at speeds suitable for generating electricity. These sources of power are inherently intermittent. Where wind and solar generation are used, power companies need to rely on alternative sources of power to generate electricity. In the United States, the alternative is usually natural gas, which consists mostly of methane. When it fully combusts, burning methane to generate a given amount of electricity creates much less greenhouse gas than burning coal to generate the same amount of electricity. But unburned methane is an extremely potent greenhouse gas. A ton of unburned methane has 80 times the warming effect of a ton of CO_2 for several decades and, even after a century, it has 25 times the heating power of a ton of CO_2. If 3% or more of the methane obtained by gas drilling leaks into the atmosphere and is not burned, then using methane to generate a given amount of electricity does more damage to the climate than burning coal. Since, in fact, considerably more than 3% of fracked methane leaks into the atmosphere, using fracked natural gas for electrical generation, is even worse for the climate than using coal (Goldstein and Quist, 82 and Mckibben, 68). It is estimated that methane presently causes 1/3 of the human generated global warming (BBC, November 2021).

A ton of nitrous oxide in the atmosphere has 265 times the amount of heating effect as a ton of CO_2. Huge amounts of nitrous oxide are released into the atmosphere by the manufacture and application of chemical (ammonia) fertilizers which, at least for the present, are necessary for the very high yields from hybrid grains which have greatly increased world food production during the last 50 years. These hybrids enabled the world to avoid the mass starvation that had been widely predicted before the Norman Borlaug and others created the "green revolution" in agriculture (Gates, 121-125).

At the present, battery technology is not nearly adequate to store enough energy in order for us to be able to rely on intermittent sources alone. Using current battery technology, it would cost about $20 *trillion* to store the amount of electricity used by humans during a single day and it would take many years to create such batteries (on these points, see Goldstein and Qvist, 68-71). At present, batteries are not used anywhere to store large amounts of electricity. Further, existing solar technology requires the extensive use of rare metals. Given current technology, it's unclear that we have enough silver and tellurium for solar energy to play the major role it plays in most plans for addressing climate change without also making extensive use of nuclear power (Partanen and Korhonen, 25). Plans to address climate change, solely by means of solar, wind, geothermal, storage batteries, and hydroelectric power, bet the future of the planet on the HOPE that there will be dramatic advances in battery and solar technology in the very near future. The problem of climate change is much too urgent for us to wait on the development of these technologies.

Nuclear Power and the Safety of Nuclear Power Plants

Nuclear power plants operate without creating any greenhouse gases. As of 2018, nuclear power generated more than half of the world's carbon-free electricity. Nuclear power has been used on very large scale in many countries. 20% of the electricity generated in the US comes from nuclear power (U. S. Energy Information Administration). Many countries in Europe such as France, Belgium, and Sweden use much more nuclear power per-capita than the US.

The extensive track record of nuclear power allows us to assess the risks that it involves. To date, the safety record of nuclear power plants is very good and *much better* than that of fossil fuels and hydroelectric power. Air pollution, caused mostly by burning fossil fuels, kills 9 million people a year (Wallace-Wells, 183 and McKibben, 19) which means that, on average, 24,600 people die *every day* because of air pollution. Large parts of India, China, and other developing countries have extremely bad air. Living in Dehli, India and breathing its air is the equivalent of smoking two packs of cigarettes a day (Wallace-Wells, 103). Many more people die *every day* (or every few days) from air pollution than all the people who have ever died because of nuclear power. Many more people have been killed by hydro-electric dams than all of the people who have ever been killed by nuclear power. 170,000 people were killed when a large dam in China failed and in 1975 and 238 people were killed by a dam failure in the US in 1972 (Goldstein and Qvist, 97). The safety record of nuclear power outside of the Soviet Union is extremely good and newer types of nuclear power plants promise to be much safer still.

The main danger posed by nuclear power plants is the risk of radiation leaks caused by overheating that causes cooling systems to fail. Nuclear plants operate at extremely high temperatures and require very reliable cooling systems. Coolant is pumped through the very hot cores of reactors which prevents them from overheating and melting. The coolant becomes extremely hot and drives turbines to generate electricity. The two most well-known nuclear accidents in the West (Three Mile Island and Fukushima) involved failures of cooling systems. In most existing nuclear plants, the coolant used is water. Water cooled nuclear plants operate at extremely high pressures, but many newer types of reactors use other kinds of coolants and don't operate at high pressure (see fn 2 below).

No one has died because of the "Three Mile Island nuclear disaster" in Pennsylvania in 1979. In this case, the cooling system for the reactor failed and the reactor partly melted down, but very little radiation escaped outside of the large concrete containment dome that enclosed the plant. There was a tremendous loss of life in Japan (more than 18,000 deaths) due to the earthquakes, the tsunami, the petrochemical accidents which they caused, and panic-driven evacuations of patients from hospitals (Goldstein and Quist, 89). But, as of March, 2021 only *one person* has died due to radiation exposure from the Fukushima Nuclear plant (BBC March, 2021). This death was announced by the Japanese government in 2018. According to the BBC:

> There were no deaths immediately during the nuclear disaster. At least 16 workers were injured in the explosions, while dozens more were exposed to radiation as they worked to cool the reactors and stabilize the plant.
>
> Three people were reportedly taken to hospital after high-level exposure.
>
> Long-term effects of the radiation are a matter of debate. The World Health Organization (WHO) released a report in 2013 that said the

> disaster will not cause any observable increase in cancer rates in the region. Scientists both inside and outside Japan believe that aside from the region immediately around the plant, the risks of radiation remain relatively low.
>
> On 9 March 2021, ahead of the 10-year anniversary, a UN report said there had been "no adverse health effects" documented among Fukushima residents directly related to the radiation from the disaster. Any future radiation-related health effects were "unlikely to be discernible" (BBC, March 2021).

Most estimates put the total number of past and future deaths from the Soviet nuclear disaster at Chernobyl at around 4000 (Goldstein and Qvist, 93; Wallace-Wells, 183; and Hansen, 196). But Greenpeace puts the number at 93,000. There are reasons to think that the Greenpeace estimate is very inflated (see Partanen and Korhonen, 54). In 2017, thirty one years after the accident, only 43 people had died because of exposure to radiation at Chernobyl (Partanen and Korhonen, 54). Soviet officials failed to provide iodine pills to local residents. This would have prevented people in the area from absorbing dangerous amounts of radioactive iodine into their thyroid glands. That absorption can cause thyroid cancer which creates much of the danger of radiation poisoning in the case of nuclear accidents. An area of about 1000 square miles around the plant has been evacuated by human beings. As of now, plants and animals in that area are thriving, despite elevated levels of radiation.

In any case, the very real past problems with older Soviet nuclear power plants are irrelevant to what we in the West should in the future. Our old nuclear power plants are much safer than their Soviet counterparts. Every US nuclear power plant includes large steel or lead enclosures around nuclear reactors to prevent the leak of radioactive gases in case of overheating. US reactors are further enclosed by massive concrete shields strong enough to withstand the impact of a fully loaded passenger airplane (Nuclear Regulatory Commission, “Containment Building”and “Aircraft Impact Assessment”). At Three Mile Island, this outer shield protected the nearby area. The Soviet power plant at Chernobyl did not have a massive protective shield of this sort.

Kerry Emanuel writes:

> Nuclear fission provides about 11 percent of global electrical energy but today it relies entirely on light water reactors that operate at high pressure and produce radioactive waste. Even so, nuclear fission is far and away the safest form of energy humankind has ever produced, with mortality per kilowatt hour generated less than that of any other energy source, including solar and wind. While much is made of events such as that at the Fukushima facility in Japan, petrochemical accidents brought about by the earthquake and tsunami killed many while no deaths[1] resulted from Fukushima's release of radioactive material... (Emanuel, 53).

Emanuel then discusses dramatic improvements in nuclear technology which will make new generations of nuclear power plants much safer than older nuclear plants:

> Yet nuclear technology has advanced significantly since light water reactors were introduced more than half a century ago. Advanced reactors operate at ambient pressure[2] and are passively safe: so they are inherently incapable of melting down. They burn fuel far more efficiently, resulting in greater power production per unit of fuel, and much less radioactive waste. They are far more environmentally benign than solar or wind, requiring much less land[3], and many of the new designs require very little water for cooling.
>
> Actual experience in countries such as Sweden and France shows that nuclear power can be ramped up to supply a large fraction of electrical energy in just 15 years. What is now lacking more than

---

[1] Several years after Emanuel wrote this, the Japanese government reported that one person had died from radiation exposure at Fukushima (BBC, March 2021).

[2] [TLC] Some newer types of nuclear reactors use molten lead as a coolant. Others use molten salt or sodium. These three types of reactors operate at much lower pressures than older water cooled reactors; and they are much safer for that reason (World Nuclear Association, December, 2020).

[3] [TLC] Wind farms require at least 250 times more land to produce a given amount of electricity than nuclear power plants; solar facilities require at least 25 times as much land area (Gates, 58).

anything else is political will (53).

The Problem of Nuclear Wastes

The problems created by the wastes from nuclear power plants are not nearly as great as is generally thought. Nuclear power creates *much much* smaller amounts of waste than other forms of energy, because nuclear fuel is incredibly compact. The nuclear fission that takes place in nuclear power plants creates more than six orders of magnitude more energy than the chemical reactions involved in burning fossil fuels. A kilogram of uranium burned in a nuclear power plant creates roughly two or three million times as much energy as burning a kilogram of coal (Marcus). Oil spills cause great harm to oceans and waterways. Fracking for methane puts huge amounts of toxic waste into the ground and often contaminates ground water.

It is instructive to compare the amount of waste produced by nuclear power plants with that produced by coal-fired plants: "For the electricity used by an American in an entire lifetime, if generated by coal, the solid waste would weigh 136,000 pounds.[4] If generated entirely by nuclear power, that lifetime of electricity would produce waste weighing 2 pounds that would fit in a soda can, only a trace of which would be long-lived waste" (Goldstein and Qvist, 117). "The entire volume of spent fuel from fifty years of American nuclear power – a source that produces one fifth of US electricity - could be packed into a football stadium piled twenty feet high" (Goldstein and Qvist, 122). Unlike the *gigantic* amounts of waste produced by burning fossil fuels, the relatively tiny amount of waste produced by nuclear power plants can be much more easily sequestered without causing any harm to humans. [This is not to deny that exaggerated fears of nuclear wastes have created difficulties for the proper storage of nuclear wastes.] There is no record of any harm to human health or the environment in the US caused by the storage of nuclear waste from power plants, nuclear propulsion systems in navy

---

[4] And much of that waste is very toxic. This figure represents only the *solid waste* produced by burning coal. Burning coal also sends huge amounts of climate-altering toxic wastes into the atmosphere. In the course of their normal operations, nuclear power plants release *zero* gaseous wastes into the atmosphere. On average, Americans produce 14.4 tons of greenhouse gases in a year (UCC). Given a 75 year average life-span, this means that (at current rates of emissions) the average American will produce 1008 tons (or 2,016,000 pounds of greenhouse gases), much of that is attributable to electrical generation.

ships, and nuclear weapons (Goldstein and Qvist, 123). Solar panels, which need to be replaced every 25 years, create huge volumes of waste (much much larger volumes to produce a given amount of electricity than nuclear power) and some of that waste is toxic (Goldstein and Qvist, 68). It is not clear that older generations of nuclear power plants create greater problems of waste disposal than solar power. In addition, there are new types of nuclear power plants capable of operating almost entirely on *already existing* nuclear wastes (see below).

Nuclear Power and Nuclear Weapons

Despite what many people fear, operating nuclear power plants *cannot* explode on anything close to the scale of nuclear bombs. To create a nuclear bomb, one needs to greatly compress a critical mass of fissile material by using chemical explosives. Most nuclear bombs include spheres with conventional explosives surrounding fissile material that is greatly compressed when the explosives are detonated. This needs to be done with great precision in order to create a workable nuclear bomb. In addition, the nuclear material used in nuclear power plants is not sufficiently concentrated to be used to create bombs. Nuclear power plants use nuclear fuel that consists of 4-5% fissionable material. Nuclear bombs, by contrast, require concentrations of fissionable material greater than 90%. It takes very sophisticated technology not located in power plants to raise or "enrich" the purity of nuclear fuel to weapons grade levels. Given the basic physics of nuclear power plants and nuclear bombs, and the technology needed to create them, it is *impossible* for nuclear power plants to create massive nuclear-bomb-like explosions in the course of their normal operations.

Still, one might ask about the connection between nuclear power and the production nuclear weapons. Isn't there a danger that greater use of nuclear power would lead to the proliferation of nuclear weapons? "Breeder" nuclear power plants create more nuclear fuel than they consume. The plutonium fuel that they produce can be used for electrical generation. In the past, this plutonium was also used to build nuclear weapons. But nuclear power plants can also do the opposite. They can generate electricity using nuclear material that already exists and make it *less dangerous* and *less useable for nuclear weapons*. At present, some power plants use material from dismantled nuclear bombs and make it less radioactive and no longer suitable for making bombs. There already exists a great deal of nuclear waste and nuclear material from dismantled weapons (World Nuclear Association, 2017). It makes abundant sense for us to use that material in power plants. Doing so creates carbon-free electricity and makes those existing materials less dangerous. So, not only can nuclear power be a major part of the solution to climate change, very surprisingly, it can also help to address the problem of the proliferation of nuclear weapons. (Thorium power plants would also help address the problem of nuclear proliferation - see below.)

Thorium

Nuclear reactors that use thorium have many advantages over existing uranium and plutonium reactors. The nuclear by-products of thorium plants are much less usable for weapons than the by-products of conventional reactors; they produce only 2% as much plutonium (Martin). Indeed, it was the unsuitability of thorium reactors for producing material for nuclear weapons that caused the US government to stop funding serious research on thorium reactors in 1974 (Stenger and Goldstein and Quist, 164). Thorium reactors would be considerably safer than existing nuclear power plants. They are designed to shut down automatically when they overheat without human operators needing to take any action. (When temperatures exceed a certain limit, or in the event of power failure, a fusible metal plug at the bottom of the reactor will melt and the liquid fuel will drain into underground tanks for where it can be safely stored (Juhasz, et. al. and Goldstein and Quist, 165)). The fuel used in thorium reactors is liquid fluoride thorium. This is an extremely simple and reliable safety system - as simple as the fuses that prevent electrical wires from overheating and causing fires. Thorium reactors would produce far less waste than uranium reactors to generate a given amount of power and that waste would less dangerous and not be as dangerous for nearly as long (Hargraves and Moir, 308-309).[5]

In addition to all of these virtues, thorium plants would be much more efficient than existing nuclear and fossil fuel power plants. A ton of thorium can produce 250 times as much energy as a ton of uranium in a conventional light water reactor (Hargraves and Moir 308). Thorium is three times more abundant than uranium. The United States has enough thorium to provide its power needs for 1000 years (World Nuclear Association "Thorium"). On balance, thorium power would probably be much better for the environment and the climate than wind or solar power.

---

[5] After 300 years the waste produced by thorium reactors would be 10,000 times less toxic than the waste from uranium nuclear reactors (Hargraves and Moir, 309)

It is likely that it would cost a great deal of money to build the first thorium power plants and the electricity they produce would probably be extremely expensive. But, given the many advantages of thorium, it would be foolish not to try to build and test thorium power plants. The US government has long subsidized the development of wind and solar power and electric cars. It should do the same for thorium.

For all of their problems, older types of nuclear power plants are arguably the most environmentally friendly forms of power that are widely used all over the world (hydroelectric and geothermal power are not feasible everywhere and can supply only a limited amount of the power we need). Bill Gates writes "[nuclear power is] the only carbon-free energy source that can reliably deliver power day and night, through every season, almost anywhere on earth, that has been proven to work on a large scale" (Gates, 84). There is every reason to think that newer types of nuclear power plants will be *much* better than the older ones. Newer generations of nuclear power plants have many virtues. Those virtues need to be a major part of the discussion of how to address climate change.

Misinformation About Nuclear Power

Opponents of nuclear power have *wildly* overstated the dangers of nuclear power and created a great deal of extremely harmful misinformation. For example, in the film *The China Syndrom,* a scientist claims that an accident at a nuclear plant "could render an area the size of the state of Pennsylvania permanently uninhabitable" (Shellenberger, 164-165). This is an extremely inaccurate claim, but it was widely accepted and cited, because the film began to be shown just 12 days before the accident at Three Mile Island. Many viewers of the film deferred to the purported expertise of a *fictional* character (Shellenberger, 209). The TV show *The Simpsons* regularly depicts extremely lax safety standards at nuclear plants resulting in widespread radiation poisoning and genetic mutations. Nothing like this has *ever* happened at an American nuclear power plant. Many people falsely believe that radiation poisoning is contagious and that it is dangerous for others to be around someone who is suffering from it (Wolchover).

Many opponents of nuclear power greatly overstate the risks of exposure to radiation and ignore that fact that some regions of the earth have very high levels of background radiation without also having increased rates of cancer. For example, the natural background radiation on the Colorado plateau is greater than most of the Fukushima area after the accident there. Radiation levels at Fukushima declined rapidly after the accident, but those on the Colorado plateau remain constant and don't seem to cause any health problems for those who live on it (Shellenberger, 169).

This misinformation and the fears it has created have had *extremely* bad consequences. Panic created by unfounded fears of radiation from the Chernobyl reactor caused 100,000-200,000 European women to terminate their pregnancies (Shellenberger, 168). After the Three Mile Island accident in 1979, there was a dramatic decline in the construction of new nuclear reactors in the US and many projects that had been planned were cancelled. As of February 2019, 6 US reactors were permanently shut down and no new electricity generating nuclear reactors were built in the US between 1996 and 2016 (World Nuclear Association, February 2019). Germany plans to close all of its nuclear power plants by 2022; As of 2017, nuclear power plants generated only 4% of Japan's electricity - in the past, that figure had been as high as 30% (World Nuclear Association, February 2019). By now, the US could easily be generating all of its electricity from carbon free sources had it expanded the construction of nuclear power plants after 1979 (see Emanuel, 60). Instead, the US and other countries built numerous coal-fired power plants. (Recently, the US has been making extensive use of fracked natural gas which is even worse for the climate than coal.) In the past, many opponents of nuclear power explicitly favored the use of fossil fuels over nuclear power. Ralph Nader was bitterly opposed to nuclear power and advocated replacing it with tar sand and shale oil, both of which are much worse for air quality and the climate than ordinary petroleum; anti-nuclear spokespeople from the Sierra Club advocated burning coal rather than nuclear power (Shellenberger, 166). The anti-nuclear movement bears considerable responsibility for our current climate crisis (Emanuel, 60).

Carbon Taxes

Economists of almost all ideological stripes think that we carbon taxes to discourage the creation of greenhouse gases and charge people who create greenhouse gases for the harm they create. Bill Gates suggests that greenhouse gas emissions should be taxed in following way. The tax for emitting a given amount of greenhouse gas should be equal to cost of directly removing an equivalent amount of greenhouse gas out of the atmosphere (Gates, 63). I think that there is much to be said for this idea.

The standard model for carbon taxes is a per-unit charge for fuel or energy use based on an estimate of the emissions they cause. For example, we might levy a tax on a gallon of gasoline based on an estimate of how much carbon using that fuel is expected to create. Recent experience in France and the United States suggests that such taxes would be extremely unpopular. If they were levied in this way, such taxes would disproportionally harm rural residents of countries like the US and Canada. Thomas Piketty argues that carbon taxes should be steeply progressive. He writes:

> A better solution would by to levy a high tax on those who produce higher levels of emission. For instance, one might offer an exemption to households emitting less than the global average and place a tax of $100 a ton on emissions above the average, then $500 a ton on emission of 2.3 times the average and $1000 (or more) on emissions above 9.1 times the average (Piketty, 668).

This system of taxation would fall heavily on large emitters, but it would not uniformly tax affluent at a higher rate than people with low incomes. Piketty's proposal would still impose high taxes on many rural people of modest means and would still be likely to be very unpopular for that reason.

A Conjecture and a Prediction About a Very Risky Alternative

Let me offer the following conjecture. If we try to combat global warming and succeed in greatly reducing emissions during the next 10-20 without making extensive use of nuclear power, we will initially create power shortages, brownouts, and frequent loss of electrical power. My reasons for thinking this are our woefully insufficient ability to store large amounts of electrical power and the great complexity of the electrical grid we would have in that case, with so many very small inputs from intermittent wind and solar generators. Many people in the environmental movement would not be bothered by this prospect; they think that we should use much less power and accept the economic austerity that would result from having less abundant and reliable power. But *that* would be extremely unpopular, particularly in a world in which there is an ever-increasing need for air-conditioning. Attempts to address global warming that involve austerity and frequent power shortages are doomed to fail in democratic societies. Per capita emissions of greenhouse gases in France and Sweden are less than a third of US per-capita emissions (Union of Concerned Scientists). France and Sweden both make very extensive use of nuclear power. Other nations can follow and improve on these examples and greatly reduce their emissions without imposing austerity on their people, provided that they make considerable use of nuclear power. Sweden makes extensive use of nuclear power and has world's highest carbon taxes (Goldstein and Qvist, 197).[6] Carbon taxes are very unpopular in many countries and some fear that they will impose great hardships on people of modest means and people in rural areas. But the Swedish economy continues to thrive and provide a very high standard of living and quality of life to all segments of Swedish society, despite Sweden's high carbon taxes.

A much cheaper way of trying to curb global warming involves "geoengineering." Kerry Emanuel explains the most widely discussed type of geoengineering under consideration:

> Proposals aimed at cooing the earth focus primarily on managing the net amount of solar radiation the planet absorbs... A popular technique involves injecting modest amounts of sulfur into the stratosphere, resulting in the formation of sulfate aerosols that reflect sunlight and thereby cool the climate system (Emanuel, 55).

Some people have proposed blocking sunlight by placing reflective tinfoil in the upper atmosphere. Trying to address global warming by blocking sunlight does nothing to address other problems created by greenhouse gases, e.g., ocean acidification (Emanuel, 56). Implementing such proposals would be extremely risky, since doing so might change weather patterns and turn heavily populated areas into deserts and might conceivably lead to wars and conflicts between nations. My own pessimistic prediction for the future is that we will not reduce or end our emissions in time, nor will we begin to remove sufficiently large amounts of greenhouse gases from the atmosphere. Rather, some nations will resort to geoenigeneering as a very low cost way abate global warming. Whether or not geoengineering will succeed, I cannot judge. But I think that it would be foolish and extremely irresponsible to bet the future of our planet on the *hope* that geoengineering will save us.

Conclusion: Reasons for Alarm and Reasons for Hope

[6] As of 2019, Sweden taxed carbon at $150 a ton. In 2016 Sweden's per capita emissions were 4.54 tons (Worldometer).

Many people deny that human activity is causing global warming, and the plans of many of those who understand the problem are quite unrealistic. President Biden wants to slowly phase out fossil fuels over the next thirty years and he supports continuing to frack natural gas. His plans for addressing global warming move things much too slowly and greatly underestimate the harm created by natural gas. As woefully inadequate as his plans are, he will have a great deal of difficulty finding enough support for them in the US Congress. As of this writing (January 2022), it seems that he will not be able to do much of anything to address climate change. To the contrary, US greenhouse gas emissions increased by 6.2% during 2021 (Plumer).

Representative Alexandria Ocasio-Cortez, the co-author of the "Green New Deal," plans to transition away from Nuclear power as soon as possible (Shellenberger, 154). Grete Thunberg dismisses nuclear power as "extremely dangerous, expensive and time-consuming" (Shellenberger, 154-155) She should know better, given Sweden's extensive use of nuclear power, which helps give it one of the very lowest per-capita emissions of any very rich nation. Planning to reach zero net emissions while abandoning enormous amounts of existing carbon-free power without even *investigating* the possibility of replacing existing nuclear power plants with newer very promising types of nuclear plants is patently absurd.

This is all very grim, but there are also reasons for hope. *Using existing technologies*, we could use nuclear, solar, wind, geothermal, and hydroelectric power, to generate ALL of our electricity from carbon free sources and use electricity to power almost everything else, e.g., heating, cooling, and transportation (Goldstein and Quist, 213-214 and Gates, 67). At present, it is not possible to power aircraft without putting carbon into the atmosphere. However, with abundant carbon free electricity, we could create very large amounts of hydrogen and oxygen through the electrolysis of water (or other processes) and use those gases to power airplanes and other modes of transportation. The result burning hydrogen and oxygen is harmless water vapor.

We need to drastically reduce, if not completely eliminate, all current emissions of greenhouse gases. As difficult as that will be, it will not be sufficient. Given the very long time that greenhouse gases remain in the atmosphere and, given the vicious feed-back mechanisms that warm the earth, the earth would continue to heat up for a long time, even if we immediately eliminated all emissions of greenhouse gases. We will also need to remove gigantic amounts of greenhouse gases from the atmosphere. Planting more trees (particularly in tropical areas) would help, but there isn't nearly enough suitable non-agricultural land for it to be possible for us to plant enough trees to do that. There are various processes by which we can remove CO_2, nitrous oxide, and methane from the atmosphere. At this time, all of them require the use of a great deal of energy. So, in order avoid catastrophic changes in the earth's climate, it is likely that we will need to create gigantic amounts of carbon free energy and use a great deal of it to remove greenhouse gases from the atmosphere. In order to create all of that carbon free energy in time we will need to greatly increase our use of nuclear power. If they prove to be feasible, thorium power-plants could be a source of almost unlimited safe and environmentally benign carbon-free power.

Sources

American Chemical Society (2021). "It's Water Vapor, Not the CO_2`,": online at https://www.acs.org/content/acs/en/climatescience/climatesciencenarratives/its-water-vapor-not-the-co2.html#:~:text=Water%20vapor%20is%20the%20most%20important%20greenhouse%20gas.&text=It's%20true%20that%20water%20vapor,instead%20controlled%20by%20the%20temperature.

BBC (March 10, 2021). "Fukushima disaster: What happened at the nuclear plant?" online at https://www.bbc.com/news/world-asia-56252695#:~:text=There%20were%20no%20deaths%20immediately,hospital%20after%20high%2Dlevel%20exposure.

BBC (November 15, 2021). "COP26: What was agreed at the Glasgow climate conference?," online at: https://www.bbc.com/news/science-environment-56901261

Climate.gov (October, 2021). "Climate Change: Atmospheric Carbon Dioxide," online at: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide#:~:text=Before%20the%20Industrial%20Revolution%20started,the%20Industrial%20Revolution%20in%201750.

Emanuel, Kerry (2018). What We Know about Climate Change, updated edition. Cambridge, Mass: MIT Press.

Evans-Pritchard, Ambrose (August 29, 2010). "Obama could kill fossil fuels overnight with a nuclear dash for thorium", The Telegraph, UK.

Evans-Pritchard, Ambrose (March 20, 2011). “Safe nuclear does exist, and China is leading the way with thorium,” The Telegraph, UK.

Gates, Bill (2021). How to Avoid a Climate Disaster. New York: Knopf: New York.

Goldstein, Joshua, and Qvist, Staffan (2019). A Bright Future. New York: Public Affairs.

Hansen, James (2009). Storms of My Grandchildren. New York: Bloomsbury USA.

Hargraves, Richard and Moir, Ralph (2010). “Liquid Fluode Thorium Reactors,” American Scientist **98** 304-313.

Juhasz, Albert J.; Rarick, Richard A.; Rangarajan, Rajmohan (Retrieved 27 October 2014). "High Efficiency Nuclear Power Plants Using Liquid Fluoride Thorium Reactor Technology" (PDF). NASA.

Marcus Stephen (2021). “Nuclear energy: how does it work, and how renewable is it?” OVO Energy online at https://www.ovoenergy.com/guides/energy-sources/nuclear-energy.

Martin, Richard (2012). Superfuel: Thorium, the Green Energy Source for the Future. New York: Palgrave–Macmillan.

McKibben, Bill (2019). Falter: Has the Human Game Begun to Play Itself Out? New York: Henry Holt.

NASA (September 2020). “The Causes of Climate Change.” online at climate.nasa.gov/causes/.

National Oceanic and Atmospheric Administration (2020). “Ocean-Atmosphere CO_2 Exchange,” online at noaa.gov.

NOAA (November 2015). "Ocean-Atmosphere CO2 Exchange,"online at https://sos.noaa.gov/catalog/datasets/ocean-atmosphere-co2-exchange/.

NOAA Research News (June7, 2021). "Carbon dioxide peaks near 420 parts per million at Mauna Loa observatory," online at: https://research.noaa.gov/article/ArtMID/587/ArticleID/2764/Coronavirus-response-barely-slows-rising-carbon-dioxide.

Nature Conservancy (2021). "Calculate Your Carbon Footprint" online at: https://www.nature.org/en-us/get-involved/how-to-help/carbon-footprint-calculator/.

Nuclear Energy Institute (July 2015), "Land needs for Wind, Solar Dwarf Nuclear Plant's Footprint."

Nuclear Regulatory Commission (March 2021). "Containment Building" online at: https://www.nrc.gov/reading-rm/basic-ref/glossary/containment-building.html.

Nuclear Regulatory Commission (June 2009). "Aircraft Impact Assessment" online at: https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0150.html.

O'Connor, John (February 9, 2021). "By 2050, Illinois would use only renewable energy under bill" online at: https://apnews.com/article/joe-biden-race-and-ethnicity-utilities-illinois-coronavirus-pandemic-52920eb870fbd604c006670888e22001.

OVO Energy.com (February 28, 2018). "Nuclear Power."

Partanen, Rauli, and Korhonen, Janne (2017). Climate Gamble. Helsinki: Amazon.

Piketty, Thomas (2020). Capital and Ideology, translated by Arthur Goldhammer. Cambridge, Mass.: Harvard University Press.

Plumer (January 10, 2022). "US Greenhouse Gas Emissions Bounced Back Sharply in 2021," New York Times.

Saving Nature (2019). "Climate Change Is Here." Online at https://savingnature.com/climate-change/?gclid=CjwKCAiA866PBhAYEiwANkIneGCpsegEqDI_rfH3MvzrCCwIyz3xPVVdUffbzUkeMux9exKqyGOVARoCtJkQAvD_BwE.

Shellenberger, Michael (2020). Apocalypse Never. New York: Harper.

Stenger, Victor J. (9 January 2012). "LFTR: A Long-Term Energy Solution?". Huffington Post. Online at https://www.huffpost.com/entry/lftr-a-longterm-energy-so_b_1192584.

Union of Concerned Scientists (January 2022). "Each Country's Share of CO_2 Emissions," online: https://www.ucsusa.org/resources/each-countrys-share-co2-emissionsucsusa.org.

US Energy Information Administration (May 21, 2020). "Illinois." online at https://www.eia.gov/state/analysis.php?sid=IL#menu.

Wallace-Wells, David (2019). The Uninhabitable Earth. New York: Tim Duggan Books.

Wolchover, Natalie (March 28, 2011). "Is Radiation Sickness Contagious?" LiveScience, online at: https://www.livescience.com/13444-radiation-exposure-contagious.html.

Woody, Todd (December 2019). "Huge amounts of greenhouse gases lurk in the oceans, and could make warming far worse." National Geographic. Online at https://www.nationalgeographic.com/science/article/greenhouse-gases-lurk-in-oceans-could-make-warming-far-worse.

World Nuclear Association (December 2020). "Generation IV Nuclear Reactors." online at: https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx.

World Nuclear Association (February 2017). "Military Warheads as a Source of Nuclear Fuel."

World Nuclear Association (February 2019). "Nuclear Power in the World Today."

World Nuclear Association "Thorium" (November 2020). https://world-nuclear.org/information-library/current-and-future-generation/thorium.aspx.

Worldometer (December, 2021). "CO2 Emissions per Capita," online at https://www.worldometers.info/co2-emissions/co2-emissions-per-capita/