THE NUCLEAR OPTION

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In a recent article in The New Yorker magazine, the author, Michael Spector, stated that "Possessing an excessive carbon footprint is rapidly becoming the modern equivalent of wearing a scarlet letter." Global warming has become a common topic of conversation in America and around the world. While it may not yet have the status of conventional wisdom, there is growing acceptance of the theory that increasing greenhouse gases in the atmosphere could lead to dramatic changes in our climate. The National Oceanic and Atmospheric Administration recently issued a report that said globally, seven of the eight warmest years on record have occurred since 2001, and the ten warmest years have all occurred since 1995. Within the last 30 years, the rate of warming is about 30 times greater than the rate of warming before 1900. The glaciers are melting, and the Arctic sea ice is receding. The Organization for Economic Cooperation and Development, based in Oslo, Norway, predicts that within two decades, unchecked environmental damage could leave half of the world's population without adequate drinking water. This sounds like scare tactics, but the citizens of our own Southwest may become believers if the water levels in Lake Mead and Lake Powell drop much further. Rising sea levels could render a huge proportion of what is now fertile coastal land uninhabitable, flooding low lying cities.

Greenhouse gases trap infrared solar energy that is reflected by the earth's surface, and act like a giant blanket around our planet. Without greenhouse gases, the temperature of the earth would average -18* C, similar to that on the surface of Mars. When considering the question of global temperature change, it must be remembered that the greenhouse gas of overwhelming concentration is the moisture in the air, and we have essentially no control of this parameter. Nature, therefore, has its own major controlling effect upon the climate, including the cycle of celestial alignment of the Earth relative to the Sun. The amount of carbon dioxide in the atmosphere is very small and is measured in parts per million. The amount, however, has been increasing steadily for the past 100 years, rising from 280ppm to its current level of 370ppm. According to the International Panel on Climate Change, its current level has not been exceeded in the last 420,000 years. How they figured that out is a mystery to me, but there it is! There are other greenhouse gases that have a stronger ability per molecule than CO_2 to cause global warming, but they are in smaller amounts in the atmosphere. These gases are methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide contributes about 60% of the human caused increased greenhouse effect. Methane has a level of only 1060 parts per billion, but it contributes about 20% of the increased greenhouse effect, because it is better at capturing infrared radiation. Methane is produced by decaying plant matter in wetlands, rice paddies, and landfills. Another major source is the digestive system of cattle, buffalo, sheep, goats and camels. The recent news of farmers in the San Joaquin Valley capturing the methane gas produced by dairies to be used for power production is a cause for celebration. We simultaneously prevent the release of methane into the atmosphere, and we decrease the amount of other fuels that must be imported to produce power. Nitrous oxide contributes about 6% of the human caused greenhouse affect, and halocarbons, such as the outlawed Freon and its cousins contribute the other 14%. Although there is some nitrous oxide in automobile exhaust, the majority comes from bacteria in the soil and oceans. Of the human caused nitrous oxide, the majority comes from the application of nitrogen fertilizers in agriculture, and the livestock industry, particularly cows, chickens and pigs. Interestingly, recent research by Nobel Laureate Paul Crutzeu suggests that emissions of nitrous oxides in the production of biofuels more than offsets the advantages that biofuels are hoped to have in terms of CO2 emissions.

The combustion of fossil fuels is by far the largest contributor to man made CO2, with much of the remainder secondary to deforestation worldwide. Even though the world's population will eventually stabilize, the modernization of societies worldwide will result in continued elevation of the atmospheric CO2, if all of those societies choose fossil fuels to heat their homes and power their industries. Current projections are that unless CO2 emissions are reduced, the global average temperature may rise about 3*C over the remainder of this century and ocean levels may rise more than two feet. It may be that in spite of all our current enthusiasm, global warming will continue anyway. Scientists have predicted that we need to dramatically reduce our CO2 emissions, not just taper them, and we may not have the will to go that far. Unlike the United States, the European Union did sign the Kyoto Protocol, pledging to reduce their emissions. Eleven years later, and the emissions from the EU are still rising.

In addition to the need to control greenhouse emissions, there are two other powerful arguments in favor of shifting away from fossil fuels. The first is the connection between air quality and health. In my practice as a radiologist, I see chest xrays every day of people suffering from asthma. There are several factors contributing to the rise in asthma, but one of them is air pollution. The Environmental Protection Agency estimates that the burning of coal for energy kills 30,000 Americans per year through lung disease. In China, that number is much higher. In addition, the mining of coal kills more than 10,000 people worldwide every year. Most of those mining deaths occur in China and the developing world, where safety conditions are reminiscent of the preunionised days of the early 20th century in the United States. But it still kills in wealthy countries; witness the death of 18 miners in West Virginia in 2006. But coal deaths do not just come from mining; they come from burning. The overall U.S. health bill for treating asthma, bronchitis and heart attacks related to air pollution is estimated at $160 billion annually, according to the Earth Policy Institute.

The second reason is economic, particularly for the United States. We currently import 55% of the oil we consume, and that is predicted to grow to 68% by 2025. At the same time, developing countries like India and China are dramatically increasing their imports. With rising demand will come higher prices, particularly if the dollar continues to weaken. We currently spend $300 billion per year on imported oil and natural gas. We spend billions more for the armed forces that protect the seaways. The money we spend for imported oil leaves our economy and is delivered to regimes that at best are hostile to the United States. Worse, some of that money is spent indoctrinating and arming the very people that are attacking Americans in Afganistan and Iraq.

So what are our options? In my opinion, conservation gives us the most immediate results. I have a cousin who has a winery in San Luis Obispo. He recently replaced all of the incandescent lights in the winery with fluorescent lights. He not only experienced a dramatic decrease in his energy consumption for lighting, he noticed a decrease in his cooling bills. Looking at the entire country, government incentives for new refrigerators, washing machines, driers, dual pane windows, and home insulation would result in a huge decrease in our use of energy. To that laundry list we should add standards for increased mileage from our automobiles and trucks. More hybrids and all electric cars are in our future. Little things can mean a lot. How about outlawing drive throughs? We have all seen lines of ten cars wasting fuel while the drivers wait for their Starbucks coffee. We as a society could insist that they simultaneously fight obesity, air pollution and global warming by actually walking into the store. In the mountain states like Montana and Utah, trucks are permitted to have three axels in the rear, allowing them to carry much more cargo per truck, without any more tire pressure on the roads. Why not adopt the same standards around the country and decrease the number of trucks on the road? Or how about this? A shipping company out of Bremen, Germany, has found that by hoisting a huge spinnaker on their freighters on the down wind routes to South America, they significant reduce the amount of fuel needed for the passage. Conservation is not sexy, but it is powerful.

We have seen remarkable progress in the technology of alternative energy sources. Wind, solar, geothermal, and even power from the tides are all sources of power that are alternatives to burning fossil fuels. They are glamorous, but at the present time they are much more expensive than burning coal. In spite of tax subsidies over the past 30 years, they collectively provide less than 5% of U.S. energy. Wind power is very appealing, and accounted for 30% of the new generating capacity that came on line in the US in 2007. In Texas, where there is lots of wind, wind power provides about 4% of the state's electricity. Denmark produces 20% of its electricity from wind power. This is due in part to the fact that solar power is less efficient in Europe than in, say, Barstow. Siemens Corporation is currently manufacturing large off shore windmills with blades 150 feet long. They have an installation in the ocean off the coast of Liverpool, England that has a total output of 90 megawatts, enough to supply over 80,000 households. The Great Plains of the United States have been called "The Saudi Arabia of Wind", so there is plenty of potential. The trouble with wind, of course, is its unpredictability. How many times have you driven over Altamont pass and seen the hundreds of windmills standing motionless? It is uncommon for a wind generator to be operating at more than 35% of capacity, and 25% is more common. This means that it is idle and not generating power for 65 to 75 percent of the time. Wind power is relatively cheap, with a cost per kilowatt hour similar to that of coal, although the best locations on land for wind power are often far from the populous areas where electricity is needed. There are other issues, including the enormous amount of land that is required to generate significant amounts of electricity. Depending upon the size of the windmill, you need 1,000 to 5,000 windmills to produce the power of one coal fired power plant. Also, windmills turning at high speed can cause the deaths of beneficial bats and migratory birds, so that is an issue that must be solved if wind power is to be significantly expanded.

How about solar? Other than the fact that it doesn't work at night and that it is extremely expensive, it is a great idea. I am all in favor of solar, particularly in commercial operations where professionals are available to clean the panels. The home installers would have us believe that distributed power, on thousands of rooftops, is the answer to our energy problems, but when you look at the numbers, it does not yet add up. The most commonly used technology is crystalline silicon wafers that convert the sun's rays into electricity. They are inefficient, and they are expensive to produce. It cost about $30,000 for enough solar panels to provide 1/3 of the electricity of an average home. What is left unsaid is that these panels will become covered with a film of dirt, smog and leaves, and their low efficiency will decrease even further. In the last few months, a company called Nanosolar has started producing a solar panel that does away with silicon. They use a special ink that is made up of a compound called copper indium gallium selenide, or CIGS, which is sprayed on a thin metal foil the thickness of aluminum foil in a process that resembles a newspaper printing press, resulting in large rolls of this foil. The plant in San Jose can manufacture several hundred feet of this foil per minute and the company is currently making its first installation in Germany. Unfortunately,the efficiency of these foils is less than that of the photovoltaic cells made from silicon, but the foil is less expensive to manufacture. Nanosolar states that they will be able to produce electricity at a price that is close to that of coal, but this has not yet been proven.

Another company that is doing very well is First Solar. They make a different kind of thin film solar panel that uses cadmium tellurium as the semiconductor. Cadmium and tellurium are by products of the mining of zinc and the refining of copper. This company is manufacturing their panels in Germany and Ohio, and selling them to developers of large scale commercial installations. Their 2007 revenue was $504 million, up from $135 million in 2006, and their stock price on Nasdaq has skyrocketed.

Through the Million Roofs Initiative, California has earmarked $3.2 billion to subsidize solar installations. These subsidies have prompted a surge in private investment, led by venture capitalists. In 2007, these investors put $654 million in 33 solar related deals in California, up from $ 253 million in 16 deals in 2006. (According to Cleantech Group).

At present, however, solar is 3 to 4 times as expensive as coal, depending on the technology. Dan Reicher of Google.org says that "We're at the dawn of a revolution that could be as powerful as the Internet revolution. The problem is that renewable energy simply costs too much." In addition to new technology such as the CIGS film that Nanosolar is producing and the cadmium tellurium product of First Solar, another approach is to make more efficient the concentration of the sun's rays to produce steam, which is then used to turn electricity generators. An installation in Boulder City, Nevada, called Nevada Solar One, has 47 miles of trough shaped mirrors that focus the sun's rays on pipes that carry a pressurized liquid that becomes extremely hot. This liquid then goes to a heat exchanger where it boils water to generate steam. The plant covers 400 acres and produces 64 megawatts of power. In order to produce enough power as a standard coal fired plant, the installation would have to cover 4,000 acres. The company is researching the idea of using molten sodium in the pipes instead of the pressurized liquid they now use, in order to increase the efficiency of the system. Molten sodium also stays hot longer, which would allow for production of electricity for a while even after the sun went down. Theoretically, this would increase the efficiency of the plant. Silicon photovoltaics produce electricity at 18 -40 cents/kwh, and coal fired plants can do it for 7 cents/kwh. By comparison, wind power is about 8 to 10 cents/kwh, hydroelectric is about 5 cents/kwh and nuclear power is 8 – 10 cents/kwh. (According to the Maryland based Institute for Energy and Environmental Research, a nuclear watchdog group founded in 1987). The California Energy Commission agrees. The Commission estimates that when considered over the lifespan of the facilities, the cost of generating electricity with a big solar installation such as Nevada Solar One costs nearly three times the cost of using a natural gas plant. The power companies, however, have been directed by the state to produce 20% of their energy from renewable sources by 2020. That may be the reason that PG&E announced last November that they will build a similar but twice as large 177 megawatt solar thermal plant in San Luis Obispo which they hope to have operational by 2010. It would produce enough electricity to power 120,000 homes. Southern California Edison has also announced plans to cover two square miles of commercial roof tops in the LA Basin that would eventually produce 250 megawatts of power, enough to power 162,000 homes.

In spite of all the public subsidies and general interest in wind and solar, these two technologies produce less than 3% of the energy in America, and the main reason for that is cost. In a recent article in the San Jose Mercury News, a UC Berkeley professor of business, Severin Borenstein, was quoted as saying "Installing solar panels on homes is an economic loser, with the costs far outweighing the financial benefit." One of the arguments that is made by the solar installation industry is that by installing solar panels on the roofs of homes throughout the state, the cost of transmission and distribution will decrease. Professor Borenstein replies that adding solar in California has not significantly lowered those costs, and at most adds only 1 or 2 percent to the value of a solar system. In spite of that, I believe that because of the concern about global warming, and the accompanying governmental subsidies, the long term outlook for solar, is, as they say, "bright." This is particularly the case for large commercial operations in places like the Mojave Desert, where we have plenty of sunlight and land. It will help us decrease CO_2 emissions, and provide a boost in electricity production during the hottest times of the day, when Americans want their air conditioners.

America currently consumes more than 20 million bbl of oil per day. In order for America to decrease its reliance on imported oil, we will need to change the way we drive. The transportation sector, so vital in our society for carrying people, goods, food and materials, relies for more than 95% of its needs on gasoline, diesel and kerosene derived from petroleum. Of the 20 million bbl per day, about 60% of that goes to the transportation sector. We also depend upon oil for the large variety of petrochemicals and derived products such as plastics, fertilizers, detergents, pharmaceuticals and synthetic fibers that today are so ubiquitous in our daily lives that we hardly think about where they come from. In order to decrease CO_2 emissons from the transportation sector, we have to increase gas mileage, with the best current technology being hybrid cars. General Electric has even developed a hybrid diesel train engine that uses the braking power of the train to power a huge battery that can produce 2,000 horsepower. They claim it will cut fuel costs and CO_2 emissions by 50%. Two other proposals are on the horizon. An electric-hybrid car is the first. The Chevrolet Volt is one idea, an electric-hybrid automobile that theoretically will perform as well as a gas powered car. If you drive less than 40 miles, you would only use the lithium-ion battery for power. On longer trips, an on board engine that could run on gasoline or ethanol would kick in to recharge the battery, extending the range to 640 miles. The battery also is designed to be recharged at home, using a regular 110 volt electric outlet. Regardless of how good these cars become, I think we can all agree that from an air pollution or climate change point of view, it does not make any sense to charge a battery with a coal fired power plant. In addition, the energy delivered to an electric car requires more hydrocarbon fuel per mile than does the direct use of hydrocarbon fuel.

The other proposal is hydrogen fuel cell technology. The advantage of hydrogen fuel cells is that the exhaust is water, not CO2. Many people speak of fuel cells as the panacea for all our transportation ills. The reality is less rosy. Although hydrogen can work as the fuel for fuel cells, hydrogen is difficult and expensive to produce. The most common method of producing hydrogen emits tons of CO2 into the atmosphere, which negates why we would be shifting to fuel cells in the first place. It is even more difficult to distribute to the people who would need it for their cars. It is explosive (remember the Hindenburg?), corrosive, and would require billions of dollars in infrastructure changes to make a hydrogen economy work. Hydrogen is very difficult to transport because it cannot be piped like natural gas. Because of its chemical properties, a tanker truck of hydrogen would carry much less than a comparable load of natural gas. The solution may be that each service station would produce its own hydrogen. This is possible, but it is expensive and would require enormous amounts of electricity to drive the chemical process, which I will describe in a moment. Then there is the prospect of convincing the public to purchase cars that have hidden within them a fuel much more explosive than gasoline. Because of these issues with hydrogen, scientists and engineers are turning their attention to methanol (CH3OH) as a substitute for hydrogen for fuel cells. Methanol is currently mainly produced from synthesis gas, which is a mixture of carbon monoxide (CO) obtained from the incomplete combustion of fossil fuels, combined with hydrogen. It can also be produced by capturing the CO2 emissions from coal and natural gas power plants and combining it with abundant hydrogen. But where would the hydrogen come from? 96% of the hydrogen used in the world today is produced from fossil fuels, with half being generated by the steam reforming of natural gas. Although relatively inexpensive, this process relies on diminishing reserves of natural gas or oil and emits large amounts of CO2. A better idea is to expand the way the other 4% of today's hydrogen comes from. That is electrolysis of water. All you need is water and lots of electricity. That is why only countries with abundant hydropower, such as Norway, or abundant geothermal power, such as Iceland, produce their hydrogen this way.

The promise of methanol is that it eventually can be produced using CO2 from the atmosphere. When combined with hydrogen manufactured from water, we will be able to produce methanol in abundance. Methanol has many other uses than just fuel cells. As the world petroleum and natural gas reserves eventually diminish in the centuries ahead, methanol can be used as the precursor for all the petrochemicals, plastics and pharmaceuticals we now use oil for.

This all sounds great, but where will all this electricity come from? Over the next few decades, global electricity consumption is expected to double. 80% of the electricity in this country comes from coal or natural gas fired power plants. We have tremendous reserves of coal in this country, probably enough to last for hundreds of years. We also have large reserves of natural gas, and 85% of the natural gas burned in this country comes from five states, Louisiana, Texas, New Mexico, Oklahoma, and Wyoming. Imports are rising, however, with majority of our imported natural gas coming from Canada. Unfortunately, electricity from coal and natural gas fired power plants accounts for one third of the country's CO2 emissions. There is talk about carbon sequestration, but the technology is in its infancy and it has not yet been proven. In January, the Department of Energy pulled the plug on the coal industry supported FutureGen project, a $1.8 billion bid to build a plant that would emit little carbon dioxide. There currently are 22 new coal fired or natural gas fired plants under construction in 14 states, and none of them have installed technology to capture or sequester the CO2. That is because there currently is no law that restricts CO2 emissions, nor is there any taxation of CO2 emissions. There are 48 more plants in 29 states that are being challenged by environmental groups. Every coal fired power plant built today will stay online for about 50 years. The lobbyists for the coal companies, who this year plan to spend $40 million this year in ads pushing for more coal plants, also have allies in the railroad industry, because railroads depend on coal shipments for a large share of their revenue. The global warming issue is not going away, however, and if we are serious about decreasing the emissions of CO2, we need to shift away from coal and natural gas as our source of electricity.

Wind and solar hold great promise, and I support the money that is being spent by our society for tax incentives and research. As I mentioned before, these two industries currently provide less than 3% of our electricity. Hydroelectricity is wonderful, but our lakes and rivers have already been dammed, and there is little chance for a significant increase in hydropower. Our power grid requires enormous, continuous power, and not just during the day or when the wind blows. In addition, if our manufacturing industries are to be competitive on a global scale, our power must not only be abundant, but also inexpensive. Unless we are willing to pay three or four times as much for our electricity as we currently do, solar power will not be a major player until the technology becomes more efficient. The reading that I have done for this paper has led me to believe that the answer is nuclear energy.

The mention of nuclear energy raises fears of accidents and proliferation, as well as terrorism. These issues deserve discussion, but I have come to the conclusion that it is not a matter of if we will have large scale nuclear energy, but rather when. Although it will not happen in the next few decades, the world eventually will run out of easily available oil and natural gas, and we must have an alternative energy source. As I mentioned earlier, future generations may eventually need to manufacture their hydrocarbons from CO2 and hydrogen, and we will need enormous amounts of electricity for the process. If climate change occurs in spite of our best efforts, we will need more electricity to power the desalination plants that will provide drinking water from the ocean.

At this moment, there are 439 reactors in 31 countries, supplying 15% of the world's electricity. Around the world, 31 reactors are under construction and many more are in the planning stages. Some of the most ambitious programs are in developing countries. Both China and India are building several reactors and intend to increase their nuclear generating capacity several times over the next 15 years. According to a September, 2007 issue of The Economist, some countries, such as Turkey and Vietnam are considering starting nuclear programs, and others, including Argentina and South Africa plan to expand their existing ones. The rich world is also examining the case for nuclear. Britain's Prime Minister, Gordon Brown, recently affirmed his support for a new generation of nuclear power plants. Construction of a new one in Finland, Western Europe's first in 15 years began in 2005, and work just began on another of the same design in France. The French company, EDF, has announced that it has plans to build four nuclear plants in England, without public funds. The first is scheduled to open in 2017. Part of the enthusiasm has to do with the fact that nuclear reactors emit none of the greenhouse gases. In addition, they are fueled by uranium, which is relatively abundant, and is available from many sources, including reassuringly stable places such as Canada and Australia.

After the oil crisis in 1973, France decided to pursue the goal of fossil fuel independence. With few energy resources of its own, pursuing nuclear power seemed the best strategy. France now has 59 nuclear power plants, producing 80% of its electricity. In the United States, there are 103 operating reactors, producing 20% of our electricity. Nuclear reactors produce their power in the same way that the core of the earth remains molten. Temperatures in the earth's core reach 7,000 degrees Centigrade, hotter than the surface of the sun. Some of this heat comes from gravitational pressures and the left over heat from the collision of astral particles that lead to the formation of the earth. At least half of that heat comes from the radioactive breakdown of thorium and uranium within the earth's mantle. This is replicated in a controlled environment in nuclear reactors. When Albert Einstein signed the letter to President Roosevelt informing him of the discovery of nuclear energy, he turned to his fellow scientists and said: "For the first time mankind will be using energy not derived from the sun." This possibility emerged in 1905, when Einstein proposed that energy and matter are different forms of the same thing, and that energy could be converted to matter and matter to energy , with the relationship described by the famous equation E = MC2. The coefficient, C2, is the speed of light squared. Since the speed of light is 186,000 miles per second, the equation signifies that a very small amount of matter can be converted into a very large amount of energy. Translating that into our need for electricity, the amount of fuel needed to produce an equivalent amount of electricity is approximately two million times smaller if we use nuclear energy, instead of coal.

For instance, at an average 1,000 megawatt coal plant, a train with 110 railroad cars, each loaded with 20 tons of coal, arrives every five days. The world burns a billion tons of coal a year, up from 500 million tons a year in 1976. Now consider a 1,000 megawatt nuclear reactor. Every two years, a fleet of flatbed trucks pulls up to the reactor to deliver a load of fuel rods. They will be loaded into the reactor where they will remain for six years. Only one third of the rods are replaced at each refueling. The replaced rods are removed and transferred to a storage pool inside the containment structure, where they can remain indefinitely (three feet of water blocks the radiation). The two reactors at Diablo Canyon have been operating for 22 years and all their used fuel rods are stored in a pool the size of a basketball court. Diablo Canyon produces 2,300 megawatts, serving the electricity needs of more than 1.6 million northern and central California homes. For a conventional power plant to produce as much electricity as Diablo Canyon does in one year, it would have to burn 20 million barrels of oil or 4 million tons of coal. With nuclear power, there is no exhaust, no carbon emissions, no sulfur sludge to be carted away hourly and heaped into vast dumps. The fuel rods come out looking exactly as they did going in, except that they are now more radioactive. There is no air pollution, no water pollution and no ground pollution.

The main objections to nuclear power are worries about an explosion or meltdown, and what to do with the waste. Concerning the first worry, it is impossible for a nuclear reactor to explode. All nuclear reactors rely on nuclear fission, a process that was discovered in the 1930's. When certain heavy atoms such as uranium are struck by a neutron, they absorb it, become unstable and split apart. This results in two lighter atoms, and two or three neutrons are ejected. The process releases large amounts of energy, much of it in the form of the kinetic energy of the fast moving fission products. This kinetic energy is converted to heat as the fission products slow down.

If the ejected neutrons go on to strike other unstable atoms nearby, those too can break apart, releasing further neutrons in a chain reaction. When enough of these neutrons produce further fissions, the process becomes self sustaining. Natural uranium is made of two isotopes, U-235 and U-238 (the latter having three more neutrons). Both are radioactive, meaning they are constantly breaking down into slightly smaller atoms, but only U-235 is fissile, meaning it will split almost in half with a much larger release of energy. Since U-235 is more highly radioactive, it has almost all broken down already, so that it now makes up only 7/10 of one percent of the world's natural uranium. In order to set off a chain reaction, natural uranium must be "enriched" so that U-235 makes up a larger percentage. Reactor grade uranium- which will simmer enough to produce heat- is three percent U-235. In order to get to bomb grade uranium- the kind that will explode- uranium must be enriched to 90% U-235. There is no way a nuclear reactor can explode.

On the other hand, a reactor can melt down. This is what happened at Three Mile Island. A valve stuck open and a series of mistakes led the operators to think that the core was overflowing with water when it was actually short of cooling water. They further drained the core and about a third of the core melted from the excess heat. But this did not result in a nuclear catastrophe. The public was worried because no one was sure what was happening, but in the end, the melted fuel stayed within the reactor vessel. Critics had predicted a "China Syndrome" where molten core would melt through the steel vessel, then through the concrete containment structure, then down into the earth where it would hit groundwater, causing a steam explosion that would spray radioactive material across a huge area. This did not happen, and the pressure vessel housing the core held. According to J. Samuel Walker, the historian of the Nuclear Regulatory Commission, virtually no radioactive gases escaped from the plant. Three Mile Island was an industrial accident, not a nuclear disaster. It bankrupted the utility, but no one was injured.

Chernobyl was a true disaster, because the Soviet design was so outmoded that a concrete containment structure was not even built around the reactor vessel. In 1986, a power surge resulted in overheating the core, which set fire to the carbon moderators of the chain reaction. American and other modern reactors do not use carbon moderators, and instead use water as the moderator. The result was a four day fire that spewed radioactive debris around the world. More fallout fell on Harrisburg, Pennsylvania from Chernobyl than from Three Mile Island. Nuclear power plants with the faulty soviet design were never built in the West, and with modern construction such an accident could not happen. In 1986, however, the public psyche was reeling from the fear of global nuclear war, and the threats from nuclear power plants were suddenly seen in the same light. The safety record of nuclear power has actually been very good. Over the 57 years since it first generated electricity in 1951, the fact remains that nuclear power has caused only a fraction of the deaths that coal causes every week. The U.S. nuclear power industry has over 3,000 operating years with only one serious accident, the one at Three Mile Island. The United States Navy has over 80 ships that operate on nuclear power, providing enormous range and propulsion. As an example of the advantages of nuclear power for the Navy, the aircraft carrier USS Enterprise had its first refueling three years after it was commissioned. During those three years, the Enterprise steamed 207,000 miles, equal to more than eight trips around the world. Since 1955, when the USS Nautilus put to sea and signaled her historic message "Underway on nuclear power", the Navy has accumulated 5,400 "reactor years" of accident free experience.

The latest generation of reactors, which evolved from models constructed in the 1970's and 1980's, include important improvements over prior designs. Westinghouse's new reactor, for example, has "passive safety" systems that can prevent a meltdown during an emergency without operator intervention. If the reactor loses pressure because of a loss of coolant, for example, pressurized tanks deliver water to the core, since the pressure in the tanks is higher than that in the core. The new reactor's simplified design also means fewer motors, pumps, and pipes are needed, reducing not only the potential for mechanical errors, but also the costs of maintenance, inspections and repairs. Westinghouse recently agreed to provide four new plants to China.

The CEO of the Nuclear Energy Institute is retired Navy Admiral Frank Bowman, who used to be the director of the Navy Nuclear Propulsion Program. In an interview with CNET news in October, 2007, he said that, "Beginning about 15 years ago there was a major, major upswing in key performance indicators of safety factors in the nation's nuclear reactors." The Nuclear Regulatory Commission conducts random inspections on these plants and conducts full blown inspections twice a year. In addition, the Commission provides at least two resident inspectors at each plant, and these inspectors have the authority to shut down the plant. According to the Bureau of Labor Statistics, there is less chance of a worker missing work due to an accident on the job in nuclear energy than in either real estate or financial services.

The other objection to nuclear power is the waste that it produces. 95% of a spent fuel rod is U-238, the same material we can find in a shovel full of dirt from our back yard. Of the remaining 5%, most is useful, but small amounts need to be stored in a safe repository such as Yucca Mountain The useful parts, U-235 and plutonium (a manmade element produced within the reactor from U-238), can be recycled as fuel. In fact, we are currently recycling plutonium from Russian nuclear missiles. Of the 20% of our electricity that we generate from nuclear power, half is produced from recycled Russian bombs. Our current federal regulations, however, require that all radioactive byproducts from our nuclear plants must be disposed of in a nuclear waste repository. As a result, more than 98% of what is scheduled to go into Yucca Mountain is either natural uranium or useful material. Canada, Britain, and France are all recycling their nuclear fuel, and this process dramatically reduces the amount of material that must be stored. Why aren't we doing this? The story is that these countries use a process that we invented in this country called "PUREX", which stands for plutonium uranium extraction. We devised that method at the beginning of the Cold War as a means to build nuclear weapons. Gerald Ford was the one who finally said " We have enough plutonium, we have enough nuclear weapons, we'll stop doing this—and if we stop, maybe we can stop the rest of the world." Jimmy Carter often gets the blame or credit for this, depending what camp you are in, but is was really Gerald Ford. The fear in 1976 was that other countries would steal our plutonium to make nuclear bombs. India had recently purchased a reactor for electricity production from Canada and then broke their promise and used that reactor to make plutonium to make their first weapon. It turns out that the countries that have built bombs have either drawn plutonium from their own reactors or have enriched their own uranium, like Iran is trying to do. In any event, we have not reprocessed fuel since 1976. Countries that do recycle their waste decrease the amount of material that needs to be stored by a factor of 20. France has produced 80% of its electricity from nuclear power for 25 years, but because France reprocesses its fuel, it stores all of its high level nuclear waste in a single (large) pool at La Hague in Normandy.

There are several new approaches to recycling nuclear waste. As part of a new 21 country multinational initiative called the Global Nuclear Energy Partnership, America's Department of Energy is supporting a type of spent fuel reprocessing which does not separate the plutonium from other highly radioactive materials in the waste, thus making it more resistant to proliferation than traditional processing. That is because if terrorists tried to steal this material, it would kill them, and the plutonium is so tightly bound it is extremely difficult to reseparate. This "Mixed Oxide Fuel" could then be turned into fuel for use in "fast" reactors. Most current reactors use water as a moderator to slow down the neutrons and are called "thermal reactors." This new generation of reactors will not use water as a moderator so the neutrons will not be slowed down, hence the name fast reactors. Fast reactors consume many of the long lived radioactive materials that current "thermal" reactors cannot. This approach could extract far more energy from a given amount of nuclear fuel while at the same time reducing the volume and toxicity of nuclear waste. Using these kinds of reactors, we have enough enriched uranium and plutonium in our missile stockpiles to run our reactors for hundreds of years. In addition, the small amount of waste would have to be stored only 500 years instead of the thousands of years of regular nuclear waste. This is still a long time, but the technical challenges in storing a smaller amount for 500 years are much lower than engineering something to be solid and secure for 10,000 years!

The U.S. currently gets 50% of its electricity from coal and 20% from nuclear reactors. Reversing these percentages should become our goal if we want to decrease CO2 emissions. The abundant electricity produced will be needed to recharge all of electric cars that are in our future. The nuclear industry has seen a resurgence in the past decade. Rising natural gas prices are increasing the demand for locally produced energy. The entire fleet of 103 reactors in America is up and running 90% of the time. Reactors are making money, so much so that the attorney general of Connecticut recently proposed a windfall profits tax on them. The industry is poised for new construction, with proposals for seven new reactors submitted to the Nuclear Regulatory Commission and dozens more in the pipeline. Two will be built in Georgia, and two others in South Carolina. Again, the manufacturer will be Westinghouse, which, by the way, was purchased by the Japanese company, Toshiba, two years ago.

Another state where nuclear power is making a comeback is Florida. At a meeting in Tallahassee two weeks ago, Florida's Public Service Commission voted to approve the state's first new nuclear plants in decades. Commission member Nathan Skop hailed the decision. "Simply put, nuclear power is a strategic investment for the state of Florida and our national security- to reduce our dependence on foreign oil and to protect our environment," he said. In America, the main impediment is public fear. According to the author William Tucker, in America, "nuclear technology is regarded as an illegitimate child of the atomic bomb, a Faustian bargain, a blasphemous tinkering with nature." It actually is none of these. It is rather a natural outgrowth of our evolving understanding of the universe. The sun has been our primary source of energy throughout human history, as we have burned wood, then coal, and now oil and natural gas. In this era of climate change, global warming and greenhouse gas concerns, nuclear deserves a seat at the table. We all would like our energy without any consequences, but all energy comes with a price. People that vociferously oppose nuclear power ignore the hazards of our current system. Using coal and natural gas to produce our electricity is causing global warming through the release of CO_2 into the atmosphere. The burning of coal costs our economy billions of dollars every year because of air pollution related illness, not to mention the deaths of miners. Although coal is slightly less expensive than nuclear now, greenhouse gas caps would make burning coal more expensive; and there is enough concern about global warming in Washington right now that such caps are considered likely. Balance those costs against a technology that produces enormous amounts of electricity, day and night, in cloudy or windless conditions, without the release of any greenhouse gases.

The goal of inexpensive solar and wind power is a worthy one that I fully support, but the time has come for us to avail ourselves of the advantages of abundant electricity produced from nuclear power.

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