An Analysis of Nuclear Energy and the Possible Solution to the Consequences of Burning Fossil Fuels

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Approximately 60% of energy production in the U.S. comes from the burning of fossil fuels, which releases harmful pollutants and carbon dioxide into the atmosphere. However, nuclear energy production, a process that does not directly release greenhouse gases, accounts for only a mere 20% (EIA, 2020). In addition to a technical comparison, one must consider how nuclear energy is viewed by the public. The devastation of past disasters, assumed relation to nuclear weapons, and unfamiliarity on the subject itself can be enough to influence the general population. Beyond the operation of a nuclear power plant, the support and supervision from government bodies play large roles in successful implementation. Specifically, the public's trust in the government and their system regarding nuclear energy is paramount (Kerr, 2011). In order to understand what is preventing nuclear energy from solving the consequences of burning fossil fuels, the following question must be addressed: how significant is the influence of perceived risk of nuclear energy and its inherently political nature on its implementation into the field of energy production?

While risk in the example of nuclear energy may be seen as a factor preventing the transition towards advanced energy production, precautionary measures can also drive the development of technology forward in other situations. So far in 2020, the COVID-19 pandemic has, in some way, affected the lives of everyone in the world, registering over 123 million cases and taking the lives of roughly 3.1 million people (Johns Hopkins, 2020). Throughout the last year, scientists and other experts have continued to learn more about this virus, including how it spreads, how long individuals remain contagious, and the best ways to slow down its spread. Additional discoveries regarding the Coronavirus, including airborne transmissions and asymptomatic cases, have instilled new levels of fear and risk in society, leading to advanced developments of masks and other personal protection equipment (PPE). The goal of my

Capstone project was to create fan powered mask system that effectively filtered both the inhalation and exhalation of virus particles, as well as one that assisted breathing and looked aesthetically pleasing.

Literature Review

According to Ulrich Beck, established risk "suggests what should not be done, not what should be done," (Beck, 2006, p. 218). Risk analysis is being used in order to understand how the general public views the dangerous nature of nuclear energy fuel and production, as well as how the fear of accidents influences its implementation into the energy industry. Additionally, the political technology framework will be applied to see how different levels of government, contribute to the process of establishing and regulating nuclear technology, as well as advocate for existing fossil fuel energy production. The question of this research paper is not objective, as there are factors that complicate the decision-making process. There are many established frameworks that guide individuals through dilemmas where there is more than one "right" answer. Moral theorists suggest different ways of looking at intentions, means, and ends in the scope of a problem. John Stuart Mill, a philosopher during the nineteenth century, would suggest consulting the Principle of Utility, reasoning that boils down to maximizing the quantity of "goodness," or utility, for the greatest number of people (Lucas & Rubel, 2015). This framework will also be used to analyze the subject of nuclear energy, for there is a complicated cost-benefit analysis regarding its implementation.

Methodologies

On the subject of environmental policy, it is important to reference the “Wicked Problems” methodology and how plausible environmental action and reform may be. In addition to environmental reform, world hunger, health care, the war on terrorism, and income disparity are examples of problems that fall into this category. Specific criteria that apply to the subject of nuclear energy implementation include the following: the problem involves many stakeholders with different priorities; the solution is one of judgement, not complete objectivity; for every solution, problems may be redirected elsewhere; the search of solutions may be infinite; the problem solvers can ultimately be held responsible for later consequences (Camillus, 2014). While there are clear benefits to completely eliminating carbon emissions, one must consider other factors, such as cost, legislation, and practicality.

Background

Human activities, including fossil fuel combustion, emit roughly 35 billion metric tons of carbon dioxide into the atmosphere, annually (Perera, 2017). According to proposed carbon budgets, total emissions must be reduced to a range of roughly 1,170 to 1,500 billion metric tons in order to limit the Earth’s warming to two degrees Celsius, which represents about 28 to 36 years based on current emissions (Mooney, 2019). In addition to carbon dioxide, the burning of fossil fuels results in pollutants, including but not limited to methane, black carbons, polycyclic aromatic hydrocarbons, and nitrogen and sulfur dioxide, which are even more effective in trapping heat in the atmosphere (Perera, 2017). Moreover, according to the World Health Organization (WHO), “urban air pollution causes seven million deaths annually, or about one in eight total deaths,” (Wilkerson, 2016). Head-to-head, coal and natural gas power plants produce 820 and 490 grams of carbon dioxide per kilowatt hour, respectively. Coal, the most common fossil fuel burned, is phasing out in energy production; however, the burning of natural gas still produces carbon dioxide and pollutant levels worth noting.

Nuclear energy production involves harvesting the energy released from the splitting of atoms in nuclear fission. This radiation is captured in the form of boiling water, which then acts as the heat source for a traditional steam power system (Office of Nuclear Energy, 2020). As a result, nuclear plants do not directly release carbon dioxide gases as would a typical coal power plant (EIA, 2020). That being said, nuclear energy is certainly not risk free. The nature of nuclear fuel, Uranium-235, is radioactive; this means the material is actively emitting harmful gamma radiation to its immediate surroundings when not properly contained (Wilkerson, 2016). Additionally, this material remains radioactive years after it is decommissioned, so hurdles arise with respect to nuclear waste storage (Jacoby, 2020). While these foreseeable challenges, such as material containment, may be safely addressed, the unforeseeable mishaps of nuclear energy can be devastating. When any component of the primary reactor system is compromised, the nuclear reaction that occurs within the reactors may no longer be controllable. In 2011, an earthquake and a tsunami near Japan resulted in the Fukushima Nuclear Disaster (Wilkerson, 2016). Generators responsible for cooling the reactors of the plant failed, which caused the components of the reactor cores to literally melt. As a result, radioactive material along with other chemicals in the plant were released into the environment (Wilkerson, 2016). In order to reduce the danger in this field of energy, nuclear engineers are constantly developing new technologies and protocols in an effort to make these plants failsafe. For example, some newer reactor generations, referred to as pebble-bed reactors, are designed to prevent uncontrollable fission and meltdowns in the event any component of the reactor system is compromised (Wilkerson, 2016). That being said, the evolution of safety measures and reactor designs is not cheap. There are economic factors in the energy industry that make competing with coal and natural gas very difficult. The construction of nuclear plants takes exceptionally long to complete and costs more than it should to be meet safety standards (Nivola, 2016). Moreover, if the industry could significantly lower these costs and reduce completion time, they still would not contend with coal-burning plants, and merely match combined-cycle gas turbine (CCGT) plants (Nivola, 2016).

Analysis

When working with materials that are innately hazardous in an industry that has a history of disastrous accidents, risk is everywhere. More importantly, the perception of this risk by the general public must be considered, for action in a situation with risk may no longer be decided solely by experts (Beck, 2006, p. 218). In the last two decades, public opinion regarding nuclear energy has been relatively positive, with roughly two-thirds of environmentalists supporting the construction of new nuclear power plants (World Nuclear Association, 2020). That being said, many Americans do not feel well-informed on the subject; a Bisconti-Quest poll in October of 2014 revealed that only 13% of Americans feel “very well-informed” and 51% “somewhat well-informed,” (World Nuclear Association, 2020). When polls become more specific, highlighting hazards of nuclear energy and past disasters, the overall support of nuclear energy implementation noticeably decreases. Surprisingly, “neighborhood polls,” or surveys of populations living in close proximity to nuclear power plants in the country, show significant levels of trust and confidence in the industry. According to a Bisconti-Quest in 2012, 89% of people living within approximately 10 miles of a nuclear power plant are confident of its safety, (World Nuclear Association, 2020). While different polls assessing the perceived risk of nuclear energy implementation can be worded with certain caveats to influence results, most polls regarding the future of nuclear energy in the United States generally show that a majority of the public understands the importance of eliminating the production of greenhouse gases.

Given the high levels of risk in the nuclear industry and the safety measures needed to be taken, it is to no surprise that there is significant involvement with political bodies. As a matter of fact, the "government (U.S.) remains more involved in commercial nuclear power than in any other industry" in the country, (World Nuclear Association, 2020). The United States Nuclear Regulatory Commission (NRC) is an independent government agency that regulates nuclear power plants and encourages a positive nuclear safety culture, a culture that includes but is not limited to personal accountability, continuous learning, effective communication, problem identification, and a questioning attitude (NRC, 2011). This supervision extends to reviewing construction permits and renewal applications, granting operating licenses, overseeing domestic uranium mines, and determining proper waste storage locations, all while operating in a budget just shy of one billion dollars ($937 million in FY18) (World Nuclear Association, 2020). The NRC has made it clear that any advanced reactor design that use significantly different fuel will result in further evaluations that "will present a range of challenges in human and technical resources," (World Nuclear Association, 2020). As more time, research, and capital is invested in improving the safety of nuclear technology, there are inevitable hurdles regarding regulation that prolong its advancement and implementation.

In addition to plant safety, legislation and regulation with respect to security is very significant. As mentioned earlier, the nature of the radioactive fuel is dangerous, making nuclear power plants targets for potential terrorist attacks. As seen in the Fukushima Nuclear Disaster, more than 150,000 people were forced to evacuate the surrounding area, and authorities suggest that it will take up to 40 years to completely clean up the accident (BBC, 2021). If an extreme group or rogue individual were to sabotage a plant, it would be devastating. The NRC routinely tests the security systems for plants, but the possibility of an attack alone still raises great concern (Taylor, 2014). In addition to the federal government having influence on the nuclear industry, state and local governments also have the power to regulate energy production. For example, to this day, a California state law enacted in 1976 still prohibits the construction of new plants without approval of means to appropriately dispose nuclear waste (World Nuclear Association, 2020). Strategy and security do not solely apply to fuel mitigation at the scene of the energy plant. Nuclear waste storage is one of the most significant challenges in the nuclear energy industry, for fuel that can no longer be used to produce energy, also known as spent fuel, is still thermally hot and radioactive, requiring careful handling and shielding (Greene, 2018). The current solution to handling spent fuel is burrowing the waste underground in secure locations, one of which being the Yucca Mountain repository project. In 1987, the federal government designated Yucca Mountain, located in Eureka County, Nevada, as the only site to be considered for a permanent disposal site of spent fuel (Nuclear Waste Office, 2015). It was considered an optimal location due to the local desert climate, geological features, and sparse population; however, the risk of seismicity, aquifer contamination, and the opposition from Nevadan residents have interfered with the project (Greene, 2018). Moreover, U.S. Rep. (now Senator) Jacky Rosen, argued that Yucca Mountain being located in the middle of multiple U.S. military installation poses threats to national security, for it is unreasonable to assume that the decades of required waste transportation would be accident free (Hagar, 2018). Currently, there is more than 70,000 metric tons of spent fuel stored at different reactor sites across the entire country, and with Yucca's max capacity being just 77,000 tons of waste, it would fill to capacity by 2036 at the current rate of waste production (Ford, 2012). This discrepancy contradicts the initial intentions of the Yucca Mountain project, for waste mitigation beyond this site in Nevada would still be necessary in the future. As a result, the politicization of this project has made further allocation of funding very difficult (Greene, 2018). The subject of nuclear waste management itself can be considered a wicked problem, for a project that has received significant amounts of funding and attention ultimately resulted in political gridlock.

It is important to consider the magnitude of the existing fossil fuel energy production industry. According to a 2016 report from the U.S. Department of Energy, approximately two million individuals were employed in the "power creation industry," 56% of which specifically relating to oil, natural gas, and coal (Williams, 2018). Although this represents a small portion of the 144 million Americans in the total workforce, many communities in the country depend on this source of labor. For example, Wyoming, West Virginia, Illinois, and other states in the Appalachian Region account for 11% of the world's total coal production (EESI, 2018). Without this dependence, these communities and local economies would struggle to contend on a national scale. State and local governments recognize this, and members and representatives of the federal government advocate on their behalf. In 2016, President Trump's victory was "propelled by carrying the (coal) mining strongholds of West Virginia and Pennsylvania," (Dlouhy, 2020). Natural gas, which surpassed coal as the top source of energy production in 2016, and oil have the same effect in other communities around the country. For example, the growth in the oil and natural gas industry resulted in North Dakota leading the country with the lowest unemployment rate and contributed to Texas totally recovering jobs lost in the Great Recession (API, 2021). While nuclear energy can also bring employment and value to communities across the country, the existing fossil fuel industry is such an integral part of many economies that solving the environmental consequences is not considered a top priority.

On the subject of nuclear energy implementation, there are benefits and drawbacks. The objective is to remove carbon emissions from energy production in order to reduce pollution, and ultimately, slow down climate change. However, when the scope of this issue extends only to the near future, the short-term consequences, including cost, employment, security, etc., complicate this decision process. How does one construct a cost-benefit analysis given the two different perspectives of looking at this issue? Utilitarian reasoning, the greatest good for the greatest number of people, would suggest that nuclear energy is the answer to maximizing utility in the long-run. While that decision in the eyes of Mill may be considered ethical, it does not consider disapproval from individuals uncertain of the risks of nuclear energy, communities dependent on fossil fuel mining and energy production, and those threatened by its relation to national security. Despite this dilemma, the U.S. continues to approve significant funding for nuclear research. Congress has allocated $1.5 billion to the Department of Energy's Office of Nuclear Energy for FY21 (World Nuclear News, 2020). Given the complexity of the problem at hand, is this funding appropriate? President and CEO of the Nuclear Energy Institute, Maria Korsnick, believes that this "demonstrates growing confidence in our nation's largest source of carbon-free energy," (World Nuclear News, 2020). While a "growing confidence" is simply optimistic, others that understand the secondary consequences of transitioning to nuclear energy may disagree with the appropriations. That being said, the continued funding and research of nuclear energy indicates intentions, at a minimum, to eventually cross this bridge, and when that time comes, it is needless to say that the decision will still be political and depend on the future perspective of what is best for the American people.

Conclusion

In the 20th century, fossil fuel energy plants made great advancements in the field of energy production that powered and expedited developing industrial societies. This breakthrough came with a significant cost, as studies have shown the negative effects of greenhouse gases on the environment. As a result, the search for means of energy production that eliminate carbon emissions, such as solar, wind, hydroelectric, and nuclear, has become a worldwide initiative. Nuclear energy, a process that can produce energy at great capacities with few direct consequences, may be the solution to this environmental crisis. However, the dangerous nature of the fuel itself and the possibility of devastating plant disasters have led nuclear energy to become a high-risk industry. Moreover, the perception of this risk by the general public and risk mitigation efforts by governments must be considered when determining if it is a plausible option. Despite past nuclear disasters and lack of complete understanding of this advanced energy form, a majority of the population is in support of nuclear energy implementation, as long as safety measures are taken with respect to plant operation, security, and waste disposal. Ultimately, the nuclear industry has answered with regulations and political involvement, but a cost-benefit analysis suggests that the price and time needed to meet these criteria is significant enough to prevent nuclear energy from competing with existing fossil fuel plants, at least in the immediate future. Environmental reform is a wicked problem, one that cannot simply be answered without additional hurdles or consequences. Despite recent technological advancements and environmental awareness, it is likely that a future where nuclear energy ultimately replaces fossil fuel plants is decades down the road.

References

American Petroleum Institute. (n.d.). How many jobs has the oil and natural gas industry created? Retrieved April 09, 2021, from https://www.api.org/oil-and-natural-gas/energy-primers/hydraulic-fracturing/how-many-jobs-has-the-oil-and-natural-gas-industry-created

BBC. (2021, March 10). Fukushima disaster: What happened at the nuclear plant? Retrieved March 22, 2021, from https://www.bbc.com/news/world-asia-56252695

Beck, U., (2006) Risk Society Revisited: Theory, Politics and Research Programmes. In The Sociology of Risk and Gambling Reader (211-227). Cosgrave, J. F.

Camillus, J. C. (2014, August 01). Strategy as a wicked problem. Retrieved April 09, 2021, from https://hbr.org/2008/05/strategy-as-a-wicked-problem

Dlouhy, J. A. (n.d.). Bloomberg.com. Retrieved April 09, 2021, from https://www.bloomberg.com/news/features/2020-09-03/trump-s-broken-coal-promises-could-cost-him-2020-election-support

Environmental and Energy Study Institute (EESI). (2018). Fossil fuels. Retrieved April 09, 2021, from https://www.eesi.org/topics/fossil-fuels/description#alternatives

Ford, A. (2012). The fight against yucca mountain. Retrieved April 09, 2021, from https://ag.nv.gov/Hot_Topics/Issue/Yucca/

Greene, R. (2018, November 15). Nuclear waste DISPOSAL Site: Yucca Mountain. Retrieved April 09, 2021, from http://large.stanford.edu/courses/2018/ph240/greene1/

Hagar, R. (2018, September 16). Yucca nuclear dump a threat to Nevada military BASES, Rosen says. Retrieved April 09, 2021, from https://lasvegassun.com/news/2018/sep/16/yucca-nuclear-dump-a-threat-to-nevada-military-bas/

Jacoby, M. (2020, March 27). As nuclear waste piles up, scientists seek the best long-term storage solutions. Retrieved October 16, 2020, from https://cen.acs.org/environment/pollution/nuclear-waste-pilesscientists-seek-best/98/i12

Johns Hopkins. (2020). COVID-19 Map - Johns Hopkins Coronavirus Resource Center. Retrieved 2 November 2020, from https://coronavirus.jhu.edu/map.html

Kerr, R. A. “Light at the End of the Radwaste Disposal Tunnel Could Be Real.” *Science*, vol. 333, no. 6039, 2011, pp. 150–152., doi:10.1126/science.333.6039.150.

Lucas, G. R., & Rubel, W. (2014). *Ethics and the military profession: The moral foundations of leadership*. Boston, MA: Pearson.

Mooney, C. (2019, July 01). Existing fossil fuel plants will push the world across a dangerous climate limit, research finds. Retrieved October 16, 2020, from https://www.washingtonpost.com/climate-environment/2019/07/01/existing-fossil-fuel-plants-will-push-world-across-dangerous-climate-limit-research-finds/

Nivola, P. (2016, July 28). The Political Economy of Nuclear Energy in the United States. Retrieved October 16, 2020, from https://www.brookings.edu/research/the-political-economy-of-nuclear-energy-in-the-united-states/

Nuclear Waste Office. (2015). Eureka County, Nevada -- Yucca Mountain. Retrieved April 09, 2021, from https://www.yuccamountain.org/purpose.htm

Perera, F. (2017, December 23). Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. Retrieved October 16, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5800116/

The Nuclear Regulatory Commission: Fact sheet. (2011). Washington, DC: USNRC, Office of Public Affairs.

Taylor, J. (2014, March 20). Nuclear power and politics. Retrieved March 22, 2021, from https://sites.psu.edu/jensci/2014/03/20/nuclear-power-and-politics/

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2020, January 15). Retrieved October 02, 2020, from https://www.eia.gov/energyexplained/nuclear/nuclear-power-and-the-environment.php

Wilkerson, J. (2016, October 25). Reconsidering the Risks of Nuclear Power. Retrieved October 16, 2020, from http://sitn.hms.harvard.edu/flash/2016/reconsidering-risks-nuclear-power/

Williams, T. (2018, November 08). Fossil has more than 50% of energy industry jobs yet Renewables drive future. Retrieved April 09, 2021, from https://www.scottmadden.com/insight/fossil-50-energy-industry-jobs-yet-renewables-drive-future/

World Nuclear Association. (2020, August). US Nuclear Power Policy. Retrieved March 21, 2021, from https://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power-policy.aspx

World Nuclear News. (2020, December 23). Congress approves nuclear energy funding FOR FY2021. Retrieved April 09, 2021, from https://www.world-nuclear-news.org/Articles/Congress-approves-nuclear-energy-funding-for-FY202#:~:text=The%20US%20Congress%20voted%20to,Energy's%20Office%20of%20Nuclear%20Energy.