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Benefits, Drawbacks, and the Path Forward for Nuclear Fission

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Abstract - In nuclear fission, a radioactive material like Uranium-235 is induced to decay into a different element, converting some of its mass into energy in the process. This process extracts stupendous quantities of energy without CO_2 emissions. Nuclear fission is safe, preserving lives and likely the environment, although more research is needed regarding radioactive waste; it creates a bonanza of high-paying jobs; and it is essential to replacing coal and combating climate change. High upfront costs are an issue, and nuclear fission requires significant government regulation and support; further research into thorium-based power may provide progress on cost. To save lives, I recommend significantly increasing nuclear power's use in the United States.

I: Introduction

Nuclear fission energy is frequently ignored in the debate between fossil fuels and renewables. Since atomic nuclei contain vastly more potential energy than chemical bonds, nuclear power is a logical step forward for harnessing clean energy.

All types of nuclear fission share the same basic process. Nuclear engineers bombard, using neutrons, an atom with a large, unstable nucleus like Uranium-235. Through the quark-interacting strong force, neutrons induce the atom to decay into a different element, releasing neutrons and losing mass in the process. [1] The lost mass is converted into energy according to the equation, $E = mc^2$; because c^2 (speed of light squared) is a large quantity, a small mass loss converts to a stupendous energy payoff. [2] Simultaneously, the released neutrons collide with other atomic nuclei, creating a chain reaction of atomic decay and energy yield. [1] Almost all nuclear plants use U-235 as fuel; during U-235's decay, around 0.085%[1] to 0.1% of its mass is converted to energy. [3][4] Experimental thorium technology uses a similar process, converting Thorium-232 into U-233, which then decays and releases energy. [5][6]

The nuclear reaction itself occurs in a reactor vessel immersed in coolant, which is "light" or regular water in the US. [1] The coolant siphons off heat from the reaction for human use, generating electricity and keeping the reaction under control. In pressurized water reactors, which make up two-thirds of all US reactors, the coolant's heat is transferred to a steam generator, boiling outside water, which then becomes steam, turns a turbine, and generates electricity. [1]

Nuclear energy is remarkably condensed. The mere 99 nuclear power plants in the US produced a whopping 809 billion kWh of energy in 2019, accounting for 19.6% of US energy production. [1][7][8] In 2019, nuclear alone produced more energy than all other renewables combined! [8]

Section II: Body

I recommend significantly increasing the use of nuclear fission energy in the United States. Nuclear fission is safe, a job-creator, and essential to ending climate change. Progress must be made on the cost front, and new research into thorium is promising.

[1] Per source 3, initial mass = 236.0021 amu and lost mass = 0.2014 amu. 0.2014 / 236.0021 = approx 0.085338%.

IIA: Safety and Environmental Considerations

Although nuclear fission is viewed negatively by some due to safety and environmental concerns, this could not be further from the truth. [9] In 2012, US nuclear fission had the lowest "deathprint" (human deaths per unit of energy produced[2]) of all energy sources; it was 1500 times less fatal than global wind power, 4400 times less than global solar, and a whopping 100,000 times less than American coal.[3] [10] US nuclear power has enough safeguards that even when things go wrong, consequences are minimal. The Three Mile Island incident, where a nuclear reactor went into partial meltdown, likely killed no one even from thyroid cancer and other secondary effects. [11]

Radioactive waste is a major concern with nuclear fission. The US produces 2,000 metric tons of such wastes each year. [1] It's uncertain how long this waste will last; estimates range between 1,000 years and 1,000,000 years for decay to acceptable levels of radioactivity. [12][13] Clearly, further research and more rigorous definitions of "acceptable" are needed. It's also uncertain how long waste containers will last; vitrified waste can probably be securely held in Yucca Mountain for between 150,000 and 1,000,000 years. [1][14][15] If waste escapes, it's unlikely to move much; after 2 billion years of rain and weathering at Oklo, a naturally-occurring nuclear site, radioactive waste migrated less than 10 meters. [15] (For comparison, coal releases so much radioactive material as fly ash that the US government has even considered using fly ash for nuclear weapons production. [9]) Unfortunately, political vacillations have meant that preparations for waste storage in the Yucca Mountain are still ongoing as the first wave of decommissionings loom. [14] The core issue with waste disposal seems political, not technological; with a supportive government, radioactive waste is likely a non-concern. [9]

Nuclear's safety derives in great part from a robust slate of environmental and economic regulations, both from the federal Nuclear Regulatory Commission, or NRC, and from state governments. Regulatory power isn't theoretical; the NRC has previously forced plant builders to change designs mid-construction to improve safety. [1] As such, I don't recommend spreading nuclear fission to states with weak governments, including much of the developing world; after all, nuclear's deathprint is 900 times higher outside the US than in. [10]

IIB: Economic Considerations

Safety regulations are necessary, but come at the cost of cost. The US government estimates nuclear fission's levelized cost of electricity (LCOE) - which factors all lifetime costs for the energy source including plant construction, operation, and decommissioning - will be $74.88 per megawatt-hour by 2025, including taxes,[4] making nuclear only slightly less expensive than coal, and 126% more expensive than photovoltaic solar![5] [16] Capital costs, like plant construction and decommissioning, account for 74.9% of nuclear's LCOE; some power plants cost $716 million to build, and construction cost overruns of 6-8 times are commonplace. [1][16] Ultimately, nuclear's high capital and overall costs stem from strict licensing and design requirements coupled with safety-induced technical complexity. [17]

Nuclear energy holds other economic benefits, employing 100,000 workers and creating another 375,000 secondary jobs nationwide, many of which are clustered in local communities. [18] These jobs pay well - in 2019, American nuclear technicians received salaries 20% higher than those of other electricity generation sources and 20% higher than America's median <u>household</u> income![6] [18][19][20] Nuclear's high-paying jobs vitalize local communities, mirroring the role coal plants have frequently had in bringing jobs and opportunities locally. [18][21][22] Nuclear can serve the same political-economic role as coal, making it a well-suited replacement.

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[2] Including deaths from accidents, air pollution, and mining for necessary raw resources.

[3] Wind: 150 deaths/trillionkWh / US nuclear: 0.1 deaths/trillionkWh = 1500; solar: 440 deaths/trillionkWh / US nuclear: 0.1 deaths/trillionkWh = 4400; US coal: 10,000 deaths/trillionkWh / US nuclear: 0.1 deaths/trillionkWh = 100,000

[4] Please refer to Table 1b, unweighted LCOE of various energy sources, in the US EIA report, source 16.

[5]($74.88 for nuclear / $33.12 for solar) - 1 = approx 1.26. Since solar's capacity factor varies unpredictably, its LCOE isn't fully comparable with nuclear fission's; the large difference in cost is clear, regardless of small variations due to capacity estimates.

[6] $82,080 / $68,703 = 1.194

IIC: Combating Climate Change

This is fortunate, as nuclear power doesn't need to economically compete with solar and wind; it must only outcompete coal. Transitioning away from fossil fuels is nonnegotiable; climate change threatens irreplaceable ecosystems and human health. [23] Climate change's strengthened heat waves alone could kill 11-73 additional people per 100,000 each year, amounting to millions of deaths worldwide. [24]

Nuclear fission energy is essential to decarbonization. It's clean - even when accounting for ancillary mining and construction emissions, nuclear power produces 4-5% as much CO_2 as natural gas per energy unit, comparable to solar. [9] More broadly, nuclear fission is essential for any decarbonified system. Solar and wind power by themselves are unreliable; the sun may not shine, and the wind may not blow, leading to energy volatility. These fluctuations decrease reliability and energy production, damaging the economy. Baseload or constant energy generation is necessary, a role nuclear fission, with an average capacity factor[7] in the US of 92.3% in 2016, is suited to fill. [9] Indeed, nuclear energy has already contributed to a 30% reduction of US electric power emissions between 2008 and 2016, preventing 564 million metric tons of CO_2 emissions in 2015 alone. [25]

IID: Thorium Technology

Research into thorium nuclear technology promises to make nuclear fission even more appealing. Liquid fluoride thorium reactors use a mixture of Th-232 and U-233 for fuel, and use liquid fluoride, not light water, as coolant. Fission begins with U-233, which releases neutrons, causing otherwise non-fissionable Th-232 to turn into U-233 and release energy. [5][6] The process generates less radioactive waste, and could potentially "breed" enough U-233 to run self-sufficiently, lowering costs. [5][6]

Thorium is also safer; liquid fluoride's boiling point, far higher than water's, makes the reactor more resilient to changes in temperature, decreasing the chance of a reactor meltdown and reducing the need for expensive cooling apparatuses. [6] As established earlier, safety regulations drive nuclear's high costs; thorium's higher safety might drive costs lower, making nuclear fission a more formidable competitor to coal and natural gas.

However, thorium power is still in development; significant gaps in research and necessary materials exist. Government support - to the tune of at least $5 billion over the next 5 years - is necessary to accelerate research and jumpstart development. [6]

IIE: Conclusions

In light of both environmental and economic considerations, I enthusiastically recommend increasing America's nuclear fission use, for three core reasons!

First, nuclear power is safe, with a deathprint[8] 1500 times lower than wind's and 100,000 times lower than coal's; with mostly technically robust protocols around nuclear waste storage; and with further thorium technological improvements on the horizon. I'd like to see more research on the durability of both waste and waste storage. Overall, substituting coal for nuclear energy will directly and immediately save lives, provided robust government enforcement of safety regulations, which limits nuclear fission use to countries with strong, relatively uncorrupt governments.

Second, nuclear power brings economic benefits, creating a plethora of high-paying jobs. However, nuclear energy faces significant cost issues; necessary safety regulations and other factors drive up nuclear's upfront capital costs, threatening to render the entire energy source uneconomical. Increased standardization, decreased plant sizes, and investments into thorium may lower costs in the future. [6][17]

Third, nuclear power is crucial for combating climate change. A clean electric system will need a reliable baseload energy source to buffer the unpredictability inherent to solar and wind power; nuclear is

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[7] The capacity factor measures how much energy is produced compared to maximum possible energy production under ideal conditions. High capacity factors, like 92.3%, indicate consistent and reliable energy generation.

[8] The number of deaths caused by a given energy source per unit of energy production

uniquely positioned to replace coal, becoming that buffer. Defeating climate change is worth the inevitable government subsidies needed to make nuclear economically competitive.

Increasing nuclear fission use will require substantive economic, regulatory, infrastructural, and research support from the government, both for uranium and thorium technologies. That's the price of progress - after all, car companies didn't build America's roads - a price not all countries can or should pay. But for the US, the payoff is high. It's time we stop sacrificing lives on the altar of cost and unfounded fears. It's time we go nuclear.

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Explicitly pro- or anti-nuclear advocacy from online advocacy groups are marked as white papers.