Funding for SMR Infrastructure and Vitrification Research

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Transmittal Letter

Dear Honored Congressman and Staff,

This aforementioned paper was written by the assigned students of Helios School's policy report on energy. Includes information on the use of funding Small Modular Nuclear Reactor (SMR) infrastructure. In addition, we also researched the use of vitrification in these newly created SMRs.

Our group researched the current energy use of the United States, along with the shortcomings of current plans. Additionally, we covered previous policies and plans regarding nuclear energy such as the Biden-Harris Administration plan, the Nuclear Waste Act Policy of 1982, and the Inflation Reduction Act of 2022. We also studied the cons of vitrification along with China's new Linglong 1 reactor.

To end this letter we must thank our group's advisors, the 7-8th grade teachers of Helios School.

We must also thank you for your time reviewing this policy report.

Sincerely,

Nikhil Venkat, Arnold Zou, Daniel Pflederer

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Executive Summary

Since 1780, the U.S.'s energy consumption has skyrocketed by a factor of 300, reaching nearly 100 exajoules today. To satisfy our energy needs, we have been burning vast amounts of fossil fuels, releasing millions of tons of CO2 into the atmosphere. In fact, in 2022, CO2 emissions from the U.S. reached 6.343 billion tons.

While there are many possible solutions to mitigate this problem, one of the most promising is nuclear energy. Nuclear fission is nearly 8,000 times more efficient at producing energy than fossil fuels. Due to its extremely high efficiency, nuclear energy requires less energy and fuel to power, creates less waste overall, and, importantly, releases negligible greenhouse gas emissions in comparison to traditional fossil fuels.

There are currently many different policies that involve nuclear energy. The Nuclear Waste Policy Act of 1982 supported deep geologic disposal of nuclear waste. Then, the Energy Production Act of 2005 made nuclear energy more affordable by allowing many nuclear power plants to get production tax credits. The Inflation Reduction Act of 2022 allocated $3.6 billion to clean energy sources, nuclear energy included. Finally, the Biden-Harris Administration Plan set goals to produce an extra 35 GW of new nuclear energy by 2035. Overall, great strides have been made towards advancing the capacity and accessibility of nuclear energy. However, there is a massive problem. China aims to reach 150 GW of capacity by 2030, putting it on track to far surpass us by 2035. It is clear that to remain competitive in the nuclear power industry, we must ramp up our expansion efforts.

SMRs (small modular reactors) are, price-wise, far superior to any other nuclear reactor. Economic modeling indicates that SMRs would effectively half the cost of producing nuclear energy. Not only that, but SMRs will create jobs, increase the U.S.'s status in the global market, and keep the U.S. as the world leader in nuclear energy. By implementing SMRs, we drive ourselves toward a greener future and a stronger economy.

One of the major downsides of nuclear energy is the nuclear waste that it produces. Currently, vitrification is the most used method for the disposal of nuclear waste. Vitrification is the process in which nuclear waste is turned into glass, with around 20% waste and 80% other resources, eliminating most environmental risks. However, vitrification is not yet at its full potential, as it releases lots of toxic gas.

Any solution to the U.S.'s energy problem must meet several criteria. First of all, it must not cause an economic recession. It must also maintain or increase the U.S.'s international status,

and maintain or grow the U.S.'s presence in the global market. Finally, it must substantially lessen CO_2 emissions while still producing adequate amounts of energy. Essentially, a solution must significantly decrease carbon emissions while either positively or neutrally affecting the U.S. economy.

Our gold standard plan for nuclear expansion would foresee an ambitious yet manageable transition to nuclear energy utilizing Small Modular Reactors and Vitrification centers. The expansion would begin with the goal of deploying 70GW of SMRs, and afterward, we would expect to keep a steady pace of 35GW per year. To deal with the nuclear waste, 5 Large-scale vitrification centers would be implemented to immobilize nuclear waste safely. SMRs are designed with existing safety features and modular containment. In case of an emergency, their small size and built-in safety systems would ensure that any release of radioactive material is safely contained, unlike larger reactors. The entire gold standard project would take approximately an upfront investment of $311.5 billion followed by a yearly investment of $159.03 billion and an addition of another $6.23 billion every year.

Our proposed policy for nuclear expansion is to implement a more reasonable transition towards nuclear energy utilizing SMRs and large-scale vitrification centers. The initial deployment would begin with the construction of 50GW of SMRs by 2030. This goal, if achieved, would put the United States at ~150 GW by 2030, which coincides with the upper end of China's goal in the same year. The extra 20 GW per year would then push us past China's upper-end rate of 18 GW per year. Even if China achieves its 150GW goal, which it will unlikely achieve, we will still surpass it in the long run using this policy proposal. Large-scale Vitrification Infrastructure would be constructed, similar to the gold standard, in 5 different areas. One designated for the Northern United States, one for the Southern United States, one for the Eastern United States, one for the Western United States, and one for the Territorial United States. Overall, the silver standard project would take an upfront investment of $237.5 billion, followed by 84.45 billion dollars the first year and an additional $4.06 billion stacking every subsequent year.
If we had attempted to achieve the same goal using our current split-up of energy, the upfront investment would be $50 billion, which is $187.5 billion less than the upfront costs with our plan. However, the annual cost of the first year after 2030 would be $39.7 billion and would increase by $8.38 billion every single year. Though both of the first values are higher in our policy, in about 26 years, according to our calculations, the fees of fossil fuel expansion will surpass those of nuclear expansion.

Overall, we believe that in the long term, even cost-wise, nuclear power is more effective at energy production. Nuclear power plants, though costly, simply don't need much maintenance, and for this simple reason, the costs don't add up as severely. We would like to request sufficient funding to be given to the development of this project and request funding for the first stepping stone to a greener future.

Problem Description

Current State

Since 1780, the U.S. 's energy use has skyrocketed from around 0.3 exajoules to nearly 100 exajoules today. Energy use in 2000 was almost ten times as great as it was in 1900 and 180 times as much as it was in 1800. [1]

This exponential growth in energy demand must, to be stable, be accompanied by an exponential growth in energy production. However, our sources and methods of producing energy are beginning to fall subpar to our needs. To support our population, we need to shift our energy split. Fossil fuels, the United States' current major energy source, are unsafe to produce, cause massive emissions, and are heavily dependent on fuel sources. Hundreds of millions lack easy access to sufficient energy, leading to negative consequences for themselves, their communities, and the environment. The current form of energy production is responsible for 87% of global greenhouse gas emissions, most of which arise from the richest countries.[2]

As a result of our unsustainable energy production practices, the world's CO2 emissions have been rising exponentially and reached 6.343 billion tons in 2022. To mitigate the effects of climate change, the greenhouse gas concentration in the atmosphere must decline towards net-zero emissions.[3]

To try to achieve this goal, the government has begun to set goals to reduce greenhouse emissions. For example, the Federal Government has set a goal to make half of all vehicles sold in the U.S. in 2030 electric vehicles and set up a network of 500,000 chargers for those EVs.[4] While certainly a noble goal, championing EVs doesn't help much to avert a climate crisis. Manufacturing the lithium-ion batteries used by the vast majority of electric vehicles, while

[1] Cleveland, C. (2023, February 20). *United States energy history in two charts*. Visualizing Energy. https://visualizingenergy.org/americas-energy-history-in-two-charts/

[2] Roser, M. (2020, December 10). *The World's Energy Problem*. Our World in Data; Global Change Data Lab. https://ourworldindata.org/worlds-energy-problem

[3] United States Environmental Protection Agency. (2023, April 11). *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. US EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

[4] US Department of Transportation. (n.d.). *Electric Vehicles & Rural Transportation | US Department of Transportation*. Www.transportation.gov. https://www.transportation.gov/rural/ev

cleaner than petroleum-based gasoline, still produces large amounts of greenhouse gases.[5] CO_2 emissions for the production of the 80kWh lithium-ion battery of the Tesla Model 3,[6] one of the most common electric vehicles,[7] range between 3,120 kg to 15,680 kg. Adding to the fact that about 60% of electricity comes from fossil fuels, electric cars aren't an effective way to mitigate climate change.

An effective solution would be a way to produce energy at a large scale while mitigating impacts on the environment. Many renewable energy sources have already been tested and implemented into the United States' current energy budget split up. Out of these, nuclear energy makes up only around 18% of our energy split.[8]

Nuclear fission(the process of energy generation that produces nuclear energy) releases immeasurably more energy than fossil fuels such as coal, gas, or oil. Nuclear fission is nearly 8,000 times more efficient at producing energy than fossil fuels. Due to its extremely high efficiency, nuclear energy requires less energy and fuel to power, creates less waste overall, and, importantly, releases negligible greenhouse gas emissions in comparison to traditional fossil fuels.[9]

On top of this, Nuclear power plants require far less maintenance than other energy generation methods. Most reactors are designed to operate for 1.5 - 2 years before they need refueling. Therefore, capacity factors of natural gas and coal are generally lower due to routine maintenance and refueling at stations. A typical nuclear reactor produces 1 gigawatt of electricity. Due to their capacity factors, natural gas plants would need to produce three to four gigawatts of electricity just to match the output of a one-gigawatt nuclear power plant. Since nuclear fission is nearly 8,000 times more efficient at producing energy than fossil fuels, this means that 24,000 fossil fuel plants of the same fuel consumption to match the output of one nuclear power plant.

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[5] United States Environmental Protection Agency. (2021, May 14). *Electric vehicle myths*. United States Environmental Protection Agency. https://www.epa.gov/greenvehicles/electric-vehicle-myths

[6] Crawford, I. (2022, March 1). *How much CO2 is emitted by manufacturing batteries? | MIT Department of Mechanical Engineering*. Meche.mit.edu. https://meche.mit.edu/news-media/how-much-co2-emitted-manufacturing-batteries

[7] Stewart, B. (2022, July 27). *10 Most Popular Electric Cars*. Kelley Blue Book. https://www.kbb.com/best-cars/most-popular-electric-cars/

[8] Center for Climate and Energy Solutions. (2018, November 27). *Nuclear Energy | Center for Climate and Energy Solutions*. Center for Climate and Energy Solutions. https://www.c2es.org/content/nuclear-energy/

[9] Jackson, A. (2018, December 5). *The Pros & Cons of Nuclear Energy*. Spring Power & Gas. https://springpowerandgas.us/blog/the-pros-cons-of-nuclear-energy-is-it-safe/

China has been utilizing the efficiency of nuclear reactors recently. Over the past decade, more than 34 gigawatts of nuclear power capacity were added to China, bringing the total amount of operating reactors in the country up to 55 with a total capacity of 53.2 GW. An additional 23 reactors are currently under construction. Though the United States has the largest current nuclear fleet, with 94 reactors, it took the U.S. forty years to add the same capacity as China added in ten years. At this rate, we are bound to be surpassed in the next decade or two.[10]

[10] U.S. Energy Information Administration. (2024, May 6). *China continues rapid growth of nuclear power capacity - U.S. Energy Information Administration (EIA)*. Www.eia.gov. https://www.eia.gov/todayinenergy/detail.php?id=61927

Current Policies

The Biden-Harris Administration Plan

In November of 2024, the Biden-Harris Administration created a plan to safely expand the amount of nuclear energy administered to the United States. Currently, this plan has nine pillars: building large gigawatt reactors, building SMRs, building microreactors, expanding and improving current reactors, improving licensing and permits, increasing the number of workers, constructing a stable supply chain of parts, constructing a stable supply chain of fuel, and managing spent nuclear fuel.[11]

This policy follows the will of the government with seven core principles: ensuring public health, preserving the environment, creating affordable energy, communicating with communities and their ideologies, respecting the sovereignty of Tribal groups, advancing environmental justice, and promoting national security.[12]

Currently, this plan plays a major role in the U.S.'s goal of net carbon neutrality by 2050. The current framework states, "Expanding domestic nuclear energy production has a key role to play in helping to avoid the worst impacts of climate change by enabling the nation to achieve a net-zero greenhouse gas (GHG) emission economy no later than 2050." All-in-all this plan has set goals to have produced an extra 35 GW of new nuclear energy by 2035. In addition, a pace of 15 new GW of energy per year should be met by 2040.[13]KOOC A TA

However, this plan, while certainly impressive, doesn't stop the rapid push of China. Currently, the U.S. has a total of 100 GW of nuclear energy production, whilst China has a total of 60 GW of nuclear energy production. The Biden-Harris administration plan creates an outline for the U.S. to have 135 GW by 2035. This would mean China only has to up its nuclear game by 75 GW, which is just two-fifths of what it already plans to achieve.

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[11] *SAFELY AND RESPONSIBLY EXPANDING U.S. NUCLEAR ENERGY: DEPLOYMENT TARGETS AND A FRAMEWORK FOR ACTION*. (2024). https://bidenwhitehouse.archives.gov/wp-content/uploads/2024/11/US-Nuclear-Energy-Deployment-Framework.pdf

[12] Ibid.

[13] Ibid.

The Nuclear Waste Policy Act of 1982

The Nuclear Waste Policy Act (NWPA) of 1982, supports the use of deep underground reservoirs for harmless storage and disposal of radioactive waste. This Act establishes methods and procedures to evaluate and select for these geologic repositories and the interaction of state and federal governments. It also provides a schedule of significant milestones that the federal agencies must reach while carrying out the program.[14]

The NWPA assigns the Department of Energy (DOE) the responsibility to site, build, and operate a deep geologic repository for the disposal of high-level radioactive waste and spent nuclear fuel, and directs the Environmental Protection Agency (EPA) to develop standards for the protection of the environment from releases of radioactive material. It also directs the Nuclear Regulatory Commission (NRC) to license the DOE to operate a repository only if it meets EPA standards.[15]

Inflation Reduction Act of 2022

In August 2022, the Inflation Reduction Act (IRA) was passed. This act provided loans and funding to many clean energy sources. In total 3.6 billion dollars were funded towards nuclear energy and other sources of energy to cover the subsidy costs.[16] In addition, it provided $700 million to stimulate the High-Assay Low-Enriched Uranium(a key party in nuclear reactors).[17] Lastly, the IRA provided $150 million to fund improvements to Idaho's National Laboratory of Advanced Test Reactor Complex and Materials Fuels Complex.[18]

Energy Production Act of 2005

The Energy Production Act of 2005 (EPA) allowed the nuclear industry to become more affordable. However, the maximum amount of money provided to reactors from PTCs cannot

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[14] United States Environmental Protection Agency. (2018, July 9). *Summary of the Nuclear Waste Policy Act*. US EPA. https://www.epa.gov/laws-regulations/summary-nuclear-waste-policy-act

[15] Ibid.

[16] World Nuclear Association. (2023, December 12). *US Nuclear Power Policy - World Nuclear Association*. World-Nuclear.org. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power-policy

[17] Ibid.

[18] Ibid.

exceed $8 billion. The EPA allowed many nuclear power plants to get production tax credits (PTC) at 1.8¢/KWh for the first 6000 MW produced.[19] Initially, it only had power plants constructed before December 31, 2020, although this was later extended; with the EPAs for the new power plants not being adjusted for inflation.

The EPA also made the overall cost of production and maintenance of nuclear reactors cheaper. It provided $2 billion of federal risk insurance for the first six high-power reactors produced after the EPA.[20] In addition, the EPA offered federal loans of up to 80% of the cost of the project.[21]

[19] Ibid.

[20] Ibid.

[21] Ibid.

Rationale

Small Modular Reactors are the Future

China's new Linglong 1 SMR

On August 13, 2023, the core module for the Linglong One nuclear reactor was moved and set in place.[22] This event was a major milestone in the development of small modular reactors (SMRs), as it meant that all the important components like the pressure vessel, evaporator, and other key equipment were installed in just one step.[23] It also cemented China's position as the leader in small modular reactor development.[24] Currently, the United States is the world leader in nuclear power, producing about 30% of the world's nuclear energy.[25] However, if China continues at this rate and achieves its goal and reaches 120 - 150 GW by 2030 it may surpass U.S. nuclear energy capacity by that year.[26] Investing in SMRs is necessary if we want to stay in the running and keep our status as the world leader in nuclear energy.

Fig. 1: The core module of the Linglong 1 SMR is lowered into place. Image courtesy of the China Atomic Energy Authority. Retrieved from https://www.caea.gov.cn/english/n6759361/n6759362/c10087720/content.html

Benefits of SMRs

Aside from aiding us in an international rivalry, SMRs present several additional benefits.

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[22] China Atomic Energy Authority. (2023, August 10). *World's first! The Heart of Linglong One is in place*. www.caea.gov.cn. https://www.caea.gov.cn/english/n6759361/n6759362/c10087720/content.html

[23] Ibid.

[24] Ibid.

[25] World Nuclear Association. (2024, August 27). *Nuclear Power in the USA - World Nuclear Association*. World-Nuclear.org. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power

[26] Gil, L. (2017, November 1). *How China has Become the World's Fastest Expanding Nuclear Power Producer*. Www.iaea.org. https://www.iaea.org/bulletin/how-china-has-become-the-worlds-fastest-expanding-nuclear-power-producer

The first major benefit that comes with SMRs is price. SMRs drastically reduce the cost of producing nuclear energy.[27] Economic modeling indicates that the total cost per kW of electricity generated by a 114 MW small modular reactor unit is $2,653 compared to $4,764 per kW for a conventional pressurized water reactor unit of 1,144 MW.[28] The total cost of a 114MW SMR would be around $303 million best case(we have assumed a cost of $450 billion to account for real-life scenarios), while the total cost of a 1,144 MW traditional reactor would be about $5.5 billion.[29] This means that converting to SMRs would effectively half the cost of producing nuclear energy.

Another important benefit of SMRs is siting flexibility. SMRs can provide clean energy where plants are not needed or sites do not have the required infrastructure to support a large unit.[30] This would include smaller electrical markets, isolated smaller grids, sites with limited water and space, or unique industrial applications.[31]

SMRs will also result in U.S. industry, manufacturing, and job growth. Because there is both a domestic and international market for SMRs and the U.S. is well positioned to compete in these markets, the development of standardized and mass-produced SMRs will likely result in an increased presence of U.S. companies in the global market.[32] If a sufficient number of SMR units were ordered, it would provide the necessary incentive to develop the appropriate factory capacity to further grow domestic and international sales of SMR power plants.[33]

SMRs are also substantially safer than standard nuclear reactors. Because they have inherent safety features like a simpler design, lower core power, and a higher proportion of coolant, in the case of an accident the operators are given an adequate time to respond.[34] SMRs also rely on simple phenomena like natural circulation for cooling, meaning these situations generally

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[27] Office of Nuclear Energy. (n.d.). *Benefits of Small Modular Reactors (SMRs)*. Energy.gov. https://www.energy.gov/ne/benefits-small-modular-reactors-smrs

[28] Dalton, D. (2020, October 15). *Generation IV / Economic Modelling Compares Costs Of SMR To Conventional PWR*. The Independent Global Nuclear News Agency. https://www.nucnet.org/news/economic-modelling-compares-costs-of-smr-to-conventional-pwr-10-4-2020

[29] Ibid.

[30] Office of Nuclear Energy. (n.d.). *Benefits of Small Modular Reactors (SMRs)*. Energy.gov. https://www.energy.gov/ne/benefits-small-modular-reactors-smrs

[31] Ibid.

[32] Ibid.

[33] Ibid.

[34] European Commission. (2024). *Small Modular Reactors explained - European Commission*. Energy.ec.europa.eu. https://energy.ec.europa.eu/topics/nuclear-energy/small-modular-reactors/small-modular-reactors-explained_en

require little to no operator support, further subtracting from the heavy demand placed on operators.[35] These passive safety systems also allow for the elimination of many components such as valves, pumps, pipes, and cables, limiting risk to the reactor due to component failure.[36]

The final benefit offered by the development of SMRs is economic growth. A 2010 study estimated that a prototypical 100MW SMR that costs $500 million to manufacture and install on-site would create 7,000 jobs and generate $1.3 billion in sales, $627 million in value-added, $404 million in earnings, and $35 million in indirect business taxes, and the annual operation of each of these SMRs would create about 375 jobs and generate $107 million in sales, $68 million in value-added, $27 million in earnings, and $9 million in indirect business taxes.[37] It also analyzed the economic impact based on 4 production rates: low (1 - 2 units/year), moderate (30 units/year), high (40 units/year), and disruptive (85 units/year), concluding that a significant impact would be realized by developing an SMR manufacturing enterprise at even moderate levels.[38]

Vitrification's Global Dominance

Currently, vitrification is the most used method for the disposal of nuclear waste.[39] Vitrification is the process in which nuclear waste is turned into glass, with around 20% waste and 80% other resources, eliminating most environmental risks.[40] The process of vitrification starts with the waste being mixed with glass-forming materials, such as silica, kyanite, wollastonite, and zircon. And other compounds (known as feed) such as sodium and potassium. This mixture is then heated at 2,100°F to form the molten glass. The molten glass is then cooled in vessels. These cooled glasses are then buried underground in a process known as grounding.[41]

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[35] Ibid.

[36] Ibid.

[37] Solan, D., Black, G., Louis, M., Peterson, S., & Arthur, E. D. (2010, June 1). *Economic and Employment Impacts of Small Modular Nuclear Reactors*. https://www.researchgate.net/publication/256064650_Economic_and_Employment_Impacts_of_Small_Modular_Nuclear_Reactors

[38] Office of Nuclear Energy. (n.d.). *Benefits of Small Modular Reactors (SMRs)*. Energy.gov. https://www.energy.gov/ne/benefits-small-modular-reactors-smrs

[39] *Vitrification - an overview | ScienceDirect Topics*. (n.d.). Www.sciencedirect.com. https://www.sciencedirect.com/topics/materials-science/vitrification

[40] Ibid.
[41] Ibid.

Vitrification is not at its Full Potential.

Firstly, vitrification releases a variety of gases, with the most common gases being water vapor, CO_2, N_2, and O_2.[42] However, the vitrification process also releases deadlier gases that negatively affect the environment, such as CO, SO_2, and N_2O.[43] These harmful gases have been measured and studied. Currently, it is nearly impossible to predict and measure how much of these gases are released into the environment and atmosphere.[44]

Secondly, the current means of vitrification cannot handle copious amounts of Molybdenum Trioxide (MoO_3) and other noble metals created from the runoff secondary waste streams.[45] These materials are hard to mold and melt into the borosilicate glass, causing an increase in the cost and a decrease in the efficiency.[46]

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[42] Ibid.

[43] Ibid.

[44] Ibid.

[45] Grayson, K. (2019, June 18). *Vitrification: The Workhorse of Nuclear Waste Management*. Mo-Sci Corporation. https://mo-sci.com/vitrification-nuclear-waste-management/

[46] Ibid.

Status Quo

Our current status quo for U.S. nuclear policies is the Biden-Harris Administration plan which aims to produce 35 extra GW of nuclear energy by 2035 and to sustain a pace of 15 extra GW of nuclear energy per year by 2040. The Biden-Harris Administration created a plan to expand the fraction of nuclear energy the US utilizes. This plan focuses on building large gigawatt reactors, SMRs, and microreactors, and would cost approximately $189 billion. However, due to China's recent nuclear capacity expansion rate, even at the pace proposed by the Biden-Harris Administration plan, the USA will fall behind. China aims to deploy (higher end of their goal) an extra 90 GW of nuclear capacity by 2030, in 5 years,[47] and plans to add 10GW per year until 2035 so they can reach a total of 200GW by then.[48] Currently, China has approximately 58GW of nuclear capacity while the USA has around 102GW.[49] If the USA follows the Biden-Harris Administration plan, by 2035, they will have 135GW of nuclear capacity in total. China would only need to deploy an extra 75GW in 10 years to surpass the USA by that time. This is a rate of 37.5 GW per 5 years, which is two-fifths of what they plan to achieve. A more drastic policy must be enforced to compete reasonably with China. If we, as the United States, want to maintain our status as the leading country in terms of nuclear energy advancement, we must raise the pace of nuclear expansion.

https://www.visualcapitalist.com/sp/ranked-nuclear-power-capacity-by-country/

https://www.nuclearbusiness-platform.com/media/insights/chinas-nuclear-power-program-a-blueprint-for-global-competitiveness

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[47] Gil, L. (2017, November 1). How China has Become the World's Fastest Expanding Nuclear Power Producer. Www.iaea.org. https://www.iaea.org/bulletin/how-china-has-become-the-worlds-fastest-expanding-nuclear-power-producer

[48] Power, N. (2024, December 10). Nuclear Business Platform. Nuclear Business Platform. https://www.nuclearbusiness-platform.com/media/insights/chinas-nuclear-power-program-a-blueprint-for-global-competitiveness

[49] Wendling, J. (2024, August 13). Ranked: Nuclear Power Capacity by Country. Visual Capitalist. https://www.visualcapitalist.com/sp/ranked-nuclear-power-capacity-by-country/

Criteria

Encourage Economic Growth

One of the largest current complaints about nuclear power plants is the hefty price tag that comes with them. The average price for a standard 1 GW nuclear power plant is approximately $5.4 billion.[50] Because of this, the Biden-Harris plan fails in that it doesn't develop nuclear capacity enough to stay ahead of China, yet also costs a total of over $189 billion just for the initial 35 GW, with another $81 billion every year. Seeing as this plan provides insignificant results while still racking up rather significant (and unnecessary) costs, the result will in all likelihood be zero or negative impacts on the economy. This result is undesirable and any policy that increases nuclear capacity must positively impact the economy.

Maintain U.S. International Status

A driving factor in our policy is to maintain the U.S.' global status as the leader in nuclear energy production. Currently, the U.S. is the dominant power in nuclear energy production.[51] Boasting 102 GW of nuclear capacity, it possesses almost twice as much current nuclear capacity as the country with the second highest capacity, France, which sits at 64 GW.[52] However, China possesses the highest prospective capacity at around 118 GW of prospective new capacity,[53] and with its new SMR technology, will soon be able to pump out nuclear energy at just half the cost of other nations.[54] The U.S. will quickly be surpassed and China will become the world leader. As maintaining international status is crucial for holding a place as a powerful nation in the world, the U.S. has to stay ahead in the nuclear race.

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[50] Plumer, B. (2016, February 29). *Why America abandoned nuclear power (and what we can learn from South Korea)*. Vox. https://www.vox.com/2016/2/29/11132930/nuclear-power-costs-us-france-korea

[51] Fleck, A. (2025, January 8). *Infographic: Who's Building Nuclear Reactors?* Statista Daily Data; Statista. https://www.statista.com/chart/33730/projected-and-currently-operating-nuclear-capacity/

[52] Ibid.

[53] Ibid.

[54] Dalton, D. (2020, October 15). *Generation IV / Economic Modelling Compares Costs Of SMR To Conventional PWR*. The Independent Global Nuclear News Agency. https://www.nucnet.org/news/economic-modelling-compares-costs-of-smr-to-conventional-pwr-10-4-2020

Drive Forward Clean Energy Production

In total, the CO_2 concentration in the atmosphere is around 420 parts per million(ppm), almost a doubling of pre-industrial CO_2 concentrations.[55] This carbon dioxide has resulted in about ⅔ of total global warming due to greenhouse gas emissions and has also acidified the ocean water from a pH of 8.21 to 8.10.[56] While this doesn't seem like much, the pH scale is logarithmic, meaning that the decrease in pH of .11 results in 29% more acidic water. Ocean acidification can create conditions that eat away at the minerals used by oysters, clams, lobsters, shrimp, coral reefs, and other marine life to build their shells and skeletons.[57] Not only that, but it can result in negative effects on human health.[58] Studies have shown that many forms of algae produce more toxins and bloom faster in acidified waters, which could harm people eating contaminated shellfish and sicken fish and marine mammals.[59] Ocean acidification also has a myriad of other negative effects on the ecosystem. The point is that CO_2 emissions have extremely negative repercussions for the ecosystem as a whole and a fossil-fuel-based energy system will eventually irreversibly damage the environment. To satisfy our exponential energy needs, we need to switch to an energy form that doesn't negatively affect the environment.

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[55] Lindsey, R. (2024, April 9). *Climate Change: Atmospheric Carbon Dioxide*. Climate.gov; National Oceanic and Atmospheric Administration.
https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

[56] Ibid.

[57] NOAA Fisheries. (2017). Understanding Ocean Acidification. Noaa.gov; NOAA.
https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification

[58] Ibid.

[59] Ibid.

Policy Recommendation

Gold Standard

Our gold standard for nuclear expansion would foresee an ambitious yet manageable transition to nuclear energy utilizing Small Modular Reactors and Vitrification centers. The expansion would begin with the goal of deploying 70GW of SMRs, which translates to approximately 614 SMR units that are 114MW in capacity each. This means deployment of around 123 SMRs is needed each year until 2030, and afterward, we expect to keep a steady pace of 35GW per year, or around 307 SMRs per year. These reactors would deliver highly reliable power at a 90% capacity factor.

To deal with the nuclear waste, 5 Large-scale vitrification centers would be implemented in geologically stable, low-population areas to immobilize nuclear waste safely. These vitrification centers would eliminate most environmental risks. The nuclear waste would be shipped to these zones and would undergo the classic vitrification process of glass forming and subsequent grounding. However, since vitrification could still benefit from improvements, dedicated research and development investments would be given to further improve waste processing technologies.

SMRs are designed with existing safety features and modular containment. In case of an emergency, their small size and built-in safety systems would ensure that any release of radioactive material is safely contained. Unlike larger reactors that, if compromised, could themselves cause a large emission of radioactive substances into the environment. The smaller and more compact SMRs, however, would themselves not be nearly as much of a hazard due to their small size and built-in self-shutdown measures.

The cost of implementing these first 614 SMRs would be in the range of $276.5 billion. The vitrification infrastructure combined with R&D would cost in the range of $15 billion. Transitioning from our current energy sources to a more nuclear approach would cost around $20 billion. In total, the initial phase of this policy would cost a total sum of $311.5 billion, or around $62.3 billion per year.

Post-2030, the SMR operating costs would come out to around $5.53 billion a year, while the vitrification operations would be around $1 billion per year. The total operating cost comes out to $6.53 billion per year. Including a simplified estimate of the annual capital cost (~$7.8 billion per year), our total operating/annual costs from our initial investments come out to be around $14.3 billion per year. Considering the annually added 35GW per year after 2030, which would require an investment of approximately $138.5 billion, additional recurring fees of around $6.23 billion per year would follow.

Overall, the entire project would take approximately an upfront investment of $311.5 billion followed by a yearly investment of $159.03 billion and an addition of another $6.23 billion every year.

Proposed Policy

Our proposed policy for nuclear expansion is to implement a more reasonable transition towards nuclear energy utilizing SMRs and Large-Scale Vitrification Centers. The initial deployment would begin with the construction of 50GW of 90% capacity SMRs by 2030, or around 439 SMRs in total (~88 SMRs per year). This goal, if achieved, would put the United States at ~150 GW by 2030, which coincides with the upper end of China's goal in the same year.[60] This means that even if China achieves its very ambitious goal (which there is a low chance it will fully do), the United States will still be on par with China in terms of nuclear capacity and will end up increasing its nuclear capacity faster than China. This part of the plan forms the core of new nuclear capacity to replace existing energy forms.

The plan after 2030 is to add 20 GW of SMR capacity annually, which translates to 175 SMRs per year. This goal is slightly more realistic than that raised in the gold standard policy, but will still be competitive with other nations such as China. This steady expansion would enable a scalable transition from current energy forms while continuously increasing low-carbon baseload power. The extra 20 GW per year would then push us past China's upper-end rate of 18 GW per year.[61]

Large-scale Vitrification Infrastructure would be constructed, similar to the gold standard, in 5 different areas. One designated for the Northern United States, one for the Southern United States, one for the Eastern United States, one for the Western United States, and one for the Territorial United States (the center would be based in Alaska). These centers would be designed to intake hoards of nuclear waste at a time, stabilize them in glass, and utilize grounding to dispose of them. A focused R&D program would be established to enhance vitrification performance and explore alternative waste forms. This effort would aim to reduce greenhouse gas emissions, minimize waste volume, and improve the long-term safety of waste storage.

As mentioned above in the gold standard section, SMRs already incorporate passive safety systems and containment structures that ensure that a chain reaction of SMR explosions does not occur. The benefits of scaling nuclear power with SMRs come to shine through this mechanism as a normal, large-scale reactor is not only more prone to failure but also causes an impact orders of magnitude greater than an SMR in the case that one does fail. SMRs will be constructed in locations that balance industrial support while meeting safety requirements.

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[60] Gil, L. (2017, November 1). How China has Become the World's Fastest Expanding Nuclear Power Producer. Www.iaea.org.
https://www.iaea.org/bulletin/how-china-has-become-the-worlds-fastest-expanding-nuclear-power-producer

[61] Ibid.

On-site and Off-site emergency protocols such as redundant backup systems, continuous monitoring, and clear evacuation plans will be established.

We would develop fast-tracked licensing for a standardized SMR design, combined with federal incentives such as production tax credits or loan guarantees. This would help overcome the high upfront costs. Funding could also come from reallocating fossil fuel subsidies and utilizing carbon pricing revenues. A Holistic Transition Plan would be incorporated in parallel with initial SMR deployment and establish policies to gradually phase out existing energy facilities. This will include decommissioning support, repurposing facilities, and economic development initiatives to aid regions historically reliant on current energy sources.

The initial build-up cost of the first 439 SMRs would cost approximately $197.5 billion. The advanced R&D in combination with the vitrification infrastructure would cost around $15 billion. Phasing out of current energy forms would cost around $20 billion, and regulatory/workforce support costs could reach $5 billion. The total initial investment would consequently total up to $237.5 billion.

The recurring SMR operating costs after 2030 would come out to $3.95 billion per year, the vitrification operating costs would come out to $1 billion per year, the regulatory costs would come with an accompanying toll of $0.5 billion per year, and the initial 50GW investment would result in $5.45 billion per year. The total cost per year to simply add 20GW annually would be $79 billion. For each added 20GW, an extra capital cost would add $1.98 billion per year, an extra operating cost would add around $1.58 billion per year, and additional support costs would total $0.5 billion per year. In total, the recurring additional stacking costs per year would be $4.06 billion.

Overall, the silver standard project would take an upfront investment of $237.5 billion, followed by $84.45 billion the first year and an additional $4.06 billion stacking every subsequent year. In simpler terms, the first year after 2030, $84.45 billion is paid. In the second year, an extra $4.06 billion is added to the initial sum per year, bringing the cost of the second year to $88.51. In the third year, another $4.06 billion is added, making the total for that year $92.57 billion. This total cost is $74 billion less than the gold standard upfront, $74.58 billion less the first year after 2030, and decreases the yearly cost annually by $2.17 billion.

If we had attempted to achieve the same goal using our current split-up of energy, the upfront investment would be $50 billion, which is $187.5 billion less than the upfront costs with our plan. However, the annual cost of the first year after 2030 would be $39.7 billion and would increase by $8.38 billion every single year. Though both of the first values are higher in our policy, in about 26 years, the fees of fossil fuel expansion will surpass those of nuclear expansion. We believe that in the long term, even cost-wise, nuclear power is more effective at energy production. Nuclear power plants, though costly, simply don’t need much maintenance, and for this simple reason, the costs don’t add up as severely.

National Relations

Switching to a nuclear-focused energy approach can have drastic effects on our energy dependencies in a couple of critical ways, benefiting not only natural security but also economic stability. Switching to nuclear power would reduce our reliance on fossil fuel imports, which, whether from natural gas or oil, come from politically shaky regions or countries with significant geopolitical leverage. This dependency exposes us to supply disruptions, sudden price shocks, and even political coercion.[62]

Nuclear power, particularly when based on SMRs, relies on uranium that can be sourced from stable and allied countries or even developed within the United States. It thereby reduces a country's import dependency and increases its energy diversity.[63]

Many renewable energy sources depend on components that are often manufactured in competing countries like China. Our imports of these are extremely vulnerable to shut-down, especially if we are competing with a country directly in the same field (energy).[64]

The United States also imports a lot of petroleum and other fossil fuel products from other countries. In 2023 alone, the United States imported about 8.51 million barrels per day of petroleum from an assortment of 86 different countries.[65]

Nuclear power would eliminate our need for as many imports for the energy field. Considering President Trump's recent tariffs on Canada, Mexico, and China would also impact renewable sources and oil imports. President Trump's order places a 25% tariff on goods from Canada and Mexico, such as solar, battery, and wind energy, and a 10% tariff on Chinese imports. It also imposes a lower levy of 10% on oil imports from Canada. With tariffs concerning renewable energy and oil imports, nuclear energy seems like the best direction for our energy split up to lean towards.[66]

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[62] *Fossil Fuels, the Economy and Instability: Why the world's dependence on fossil fuels hurts the economy and creates instability*. (2022, March 15). Generation Investment Management. https://www.generationim.com/our-thinking/insights/fossil-fuels-the-economy-and-instability-why-the-world-s-dependence-on-fossil-fuels-hurts-the-economy-and-creates-instability/

[63] World Nuclear Association. (2024a, April 16). *Nuclear Power and Energy Security - World Nuclear Association*. World-Nuclear.org. https://world-nuclear.org/information-library/economic-aspects/nuclear-power-and-energy-security

[64] Myllyvirta, L. (2025, January 9). *Why China's clean energy need not fear US tariffs – Centre for Research on Energy and Clean Air*. Centre for Research on Energy and Clean Air. https://energyandcleanair.org/why-chinas-clean-energy-need-not-fear-us-tariffs/

[65] U.S. Energy Information Administration. (2016). *How much petroleum does the United States import and export? - FAQ - U.S. Energy Information Administration (EIA)*. Eia.gov. https://www.eia.gov/tools/faqs/faq.php?id=727&t=6

[66] Storrow, B. (2019). *Scientific American*. Scientific American. https://www.scientificamerican.com/article/trump-tariffs-potential-clean-energy-effects-explained/

Recommendations

SMR Recommendations

We highly recommend our Silver Standard. It requires much less time, energy, effort, and money. However, to implement this goal we have to discuss some concrete steps. At the pace of the first 5 years of our Silver Standard, the U.S. would have to build 90 SMRs every year and spend 26.5 billion dollars per year (although this estimate could easily be more) to produce the 10 GWs of energy required per year.

The money currently is not an issue, with the U.S. spending trillions of dollars per year.[67] This means that allocating a fraction of the government's funding could be enough to cover the costs. However, the physical space to build the SMRs is more of a problem. We recommend that these SMRs be built in three main places: near existing plants, industrial hubs, and decommissioned fossil fuel sites.

Take Beaver Valley, a pre-existing site with two nuclear plants near Pittsburgh, Pennsylvania.[68] Building SMRs in this region could allow a more streamlined building experience, with little to no resistance from the community. Another option would be to develop plants near the Davis-Besse nuclear plant, a plant located in north Ohio, serving the same benefits that producing a plant near Beaver Valley would give.[69]

As for producing plants, near industrial hubs such as places near the Great Lakes or the Gulf Coast could work perfectly.[70] However, this raises the concern of safety, in the case of a meltdown normal power plants affect everywhere in a 50-mile radius.[71] However, SMRs are different, as their enhanced safety features drastically reduce the risk of a complete meltdown.

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[67] U.S. Treasury. (2024). *Fiscal Data Explains Federal Spending*. Fiscaldata.treasury.gov. https://fiscaldata.treasury.gov/americas-finance-guide/federal-spending/

[68] World Nuclear Association. (2022). *United States Of America - Reactor Database - World Nuclear Association*. World-Nuclear.org. https://world-nuclear.org/nuclear-reactor-database/summary/United%20States%20Of%20America

[69] Ibid.

[70] Ibid.

[71] *Nuclear | Ready NC*. (2022). Readync.gov. https://www.readync.gov/stay-informed/north-carolina-hazards/nuclear

Thirdly, and finally, producing SMRs in decommissioned fossil fuel plants. Over the past few years, countless fossil fuel plants have been shut down.[72] This creates extra space to build up new, more environmentally friendly, energy plants. In addition, this will encourage the phasing out of fossil fuels in the U.S., subsequently slowing down the looming threat of climate change.

After the first 5 years commence, we recommend continuing to develop SMRs in the recommended places to sustain our rate of 20 GWs per year. We also predict that developing the SMRs will give us an insight into how we can streamline the development process.

Vitrification Recommendations

This covers the SMR portion of the first 5 years of our Silver Standard. But we still have to cover the vitrification part of our policy.

We recommend the construction of 5 regional large-scale vitrification. One in the northern part of the country, one in the southern part, one in the eastern, one in the western, and finally one in the central part of the U.S. In addition, all of these plants should be in reasonably low-population areas. Vitrification plants have an estimated cost of 15 billion dollars, with our recommendation of adding a cost of 5 billion dollars in vitrification research.

As for the timeline for developing these plants, the central vitrification should be developed first, ideally around 2027-2028, with the hardline of 2030. This will provide a solid way to dispose of nuclear waste. After this, the other 4 plants should be developed by 2035, with the first of these 4 plants being produced in the first area with a major amount of SMRs.

Other Recommendations

General Public

The upfront cost of the materials of the SMRs and Vitrification plants is only part of the actual cost. We need people to build and run these plants, and these people need to be paid good money. This is why we recommend a portion of DOE's funding be transferred into salaries for the countless people working and building these plants. During 2024 just under 52 billion

[72] U.S. Energy Information Administration. (2024a, February 20). *Retirements of U.S. electric generating capacity to slow in 2024 - U.S. Energy Information Administration (EIA)*. Www.eia.gov. https://www.eia.gov/todayinenergy/detail.php?id=61425

dollars was funded for DOE.[73] A typical power plant employs 500-800 workers.[74] Assuming a low salary for such a job to be 20 dollars an hour and an SMR to have 600 workers we can calculate 12,000 dollars an hour in salaries. This totals 288,000 dollars in a 24-hour day or 105 million dollars in salaries per year.

In addition to this, a nationwide announcement should be made to educate the public about SMRs and their benefits. While also educating the public on vitrification, what it is, and how in the future it could become a promising field to study. Another major goal of this announcement should be to encourage the public about the importance of these SMRs, and how these SMRs can be beneficial to America's development.

Safety

We recommend creating policies in the case of a meltdown. This includes both on-site and off-site precautions.

On-site precautions should include excess water reserves, with real-time monitoring to ensure that the least amount of harm is done in case of a meltdown. In addition, an automatic way to shut down the plant should be available.

On the other hand, off-site precautions should include communicating with local towns to create an emergency plan in case a nearby plant malfunctions. Nearby emergency services should also routinely practice to ensure preparedness.

Overall a safety guideline should be prepared to prevent unnecessary harm to workers.

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[73] *Department of Energy FY 2024 Budget in Brief*. (2023). https://www.energy.gov/sites/default/files/2023-03/doe-fy2024-budget-in-brief.pdf

[74] Nuclear Energy Institute. (2017). *Jobs*. Nuclear Energy Institute; Nuclear Energy Institute. https://www.nei.org/advantages/jobs

Conclusion

In conclusion, we believe that our goal of an initial 50 GW of additional nuclear energy and a pace of 20 GW per year after that is the best balance of feasibility and magnitude. Not only does this plan easily keep pace with and surpass China's nuclear capacity, it does so without negatively impacting the economy. The variety of benefits offered by SMR technology and nuclear energy, in general, make it an extremely efficient and valuable energy source. Turning down this opportunity will set the U.S. behind several other countries and we will quickly lose our global dominance in nuclear energy. Not only that, but without SMR technology our large-scale reactor-based energy source will be much more pricey, inflexible, and dangerous than the more developed small modular reactors of other nations. All things considered, if the U.S. chose to invest in small modular reactor technology it would vastly benefit us as a nation and pave the way for a safe, powerful, and carbon-free energy future.

Appendices

Appendix A - Grouting/Cementation

Grouting, a form in which nuclear waste is turned into concrete, can be an alternative to vitrification. With many people stating that grouting could be potentially cheaper than vitrification.[75] However, the process of grouting is a much more recent thought, with vitrification already being used on a more widespread scale.**[76]** For this main reason, the U.S Hanford Site is opposed to the idea of switching from vitrification to grouting. They stated, "Once research and development and design engineering are completed to support transparent, credible cost, and schedule estimates, we will certainly find out grout is much more difficult, expensive, and time consuming than advertised. Don't rush to the pub tomorrow unless you've got beer money—it won't be free." **[77]** This paper follows a similar thought process, research the safer option of vitrification, and if we have more resources research grouting.

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[75] lizm. (2023, March 22). *Hanford Challenge*. Hanford Challenge. https://www.hanfordchallenge.org/inheriting-hanford/2023/3/17/should-we-grout-tank-waste-at-hanford

[76] *Department of Energy FY 2024 Budget in Brief*. (2023). https://www.energy.gov/sites/default/files/2023-03/doe-fy2024-budget-in-brief.pdf

[77] Ibid.

Appendix B - Our Bronze Standard

However, even this more feasible goal could quickly become difficult to achieve. This is why we propose a Bronze Goal, one that is slightly more than the status quo yet allows the U.S. to remain in the nuclear game. As stated before, the Biden-Harris plan wanted to deploy 35 extra GWs of nuclear energy by 2035, or an average pace of 3.5 GWs per year. On the other hand, our Bronze Plan would have the deployment of 25 GWs of energy deployed by 2035. This translates to 4 GWs, 35 SMRs, and a cost of 10.6 billion dollars per year. As for the subsequent years, 2035-2040 would consist of a deployment of 17 GWs of energy per year.

In total, this would result in 125 new GWs of energy by 2040, totaling the U.S.'s nuclear energy to 225 GWs of nuclear energy.

As for vitrification, we recommend only developing 3 core vitrification centers. One in the south, one in the northwest, and one in the northeast. Note that the center in the northeast should be skewed farther to the east to compensate for the high amount of cities in the east. This will allow most nuclear waste to be disposed of. On top of this, we recommend remaining around the 5 billion dollar mark in research and development. Even in our bronze standard, researching vitrification could make any amount of vitrification centers more efficient.

Our other recommendations remain. Such as SMRs should still be developed in the three key areas; pre-existing nuclear sites, places near industrial hubs, and decommissioned fossil fuel plants. In addition, educating the general public will become less urgent, yet we still highly recommend it.

Overall our safety recommendations remain, as it still will be important to develop on-site and off-site precautions with a national evacuation guideline that all SMRs have to follow.

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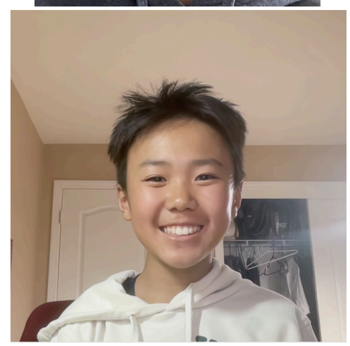
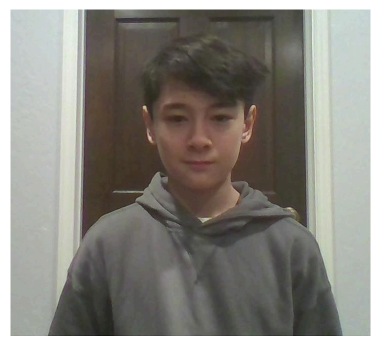


Daniel Pflederer is a 7th-grader attending Helios School in Sunnyvale, California. He enjoys a variety of topics, from mathematics to wushu. Daniel has a passion to learn more about topics such as psychology and sociology.



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