Preventing Splitting in the United States' Clean Energy Future: Policy Options to Ensure Longevity of the Domestic Nuclear Power Industry

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ABSTRACT

The nuclear energy industry in the United States has struggled to stay afloat financially due to extraordinarily high construction and financing costs, leading reactors to retire prematurely. These closures leave massive gaps in clean energy production, inherently jeopardizing the ability of the U.S. to reach net-zero emissions by 2050 in accordance with the Paris Agreement. The federal government should take initiative to help struggling nuclear facilities to maintain its current output and reverse the current backsliding the industry is experiencing. This essay discusses two policy options, including a subsidy for nuclear facility construction and an enhanced nuclear production tax credit. As electricity demand continues to grow into the future, federal investment in domestic nuclear energy would yield significant benefits for energy infrastructure and technological advancement and help mitigate the climate crisis.

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ACKNOWLEDGEMENTS

The author would like to thank his entire editorial team that worked tirelessly to get this and every other paper in top shape for this year's volume, including Mairead Crotty, Evan Linett, Kody Keckler, and Dr. Peter Linquiti. Their advice and wisdom was greatly appreciated and made this piece far more impactful. He would also like to thank Eric Meyer for his tutelage in the field of nuclear advocacy and Dr. Anil Nathan whose course provided the framework for this paper. Finally, thanks to his family for their love and support, especially his Mom and Dad, pushing him to achieve great heights in everything he does and always standing by him along the way.

INTRODUCTION

Nuclear energy is the result of billions of dollars in U.S. and international investment and millions of hours in research and development, a byproduct of drive and ingenuity following the Second World War. By harnessing the power of our universe's smallest building blocks, scientists have been able to build upon and improve the quality and efficiency of energy production domestically and abroad through nuclear energy. Despite the tremendous progress in deployment and innovation the industry has seen since its inception, many U.S. nuclear energy production facilities are slowly being phased out or retired early while many more struggle to cover costs and generate power. Today, the proliferation of the U.S.'s largest, most reliable, and most efficient source of clean energy is declining despite a greater need than ever for zero-emissions electricity.

Unfortunately, for most nuclear power plants, the decision to cease operations does not originate in a lack of fuel, skilled labor, or machinery to produce electricity. Rather, these decisions are almost always due to budgetary constraints or other economic factors. Designing, constructing, operating, and sustaining nuclear power plants are no small feats logistically and are incredibly costly long-term endeavors. While nuclear facilities can be some of the most lucrative electricity producers in the country, it takes several years or even decades to realize this profit. Thus, without stable and vast supplies of front-loaded capital, these projects often become delayed, over budget, or canceled altogether. Furthermore, as inflation continues trending upwards and natural gas and renewables become cheaper, securing tax breaks or additional capital to help achieve profitability has become more difficult for nuclear plants. The federal government has the means and the incentive to use economic policy tools such as providing subsidies or production tax credits to utility providers to accelerate nuclear fleet modernization. Without nuclear energy in the mix, achieving critical international climate goals such as net-zero emissions by 2050 is unrealistic. This essay will examine the current state of the domestic nuclear energy industry in the United States and two potential policy options to secure nuclear's vital position in our energy mix.

NUCLEAR ENERGY BACKGROUND AND BACKSLIDING

Nuclear energy is a critical part of the current U.S. energy mix, producing 20 percent of the entire country's electricity and over half of the country's clean energy. With approximately 93 reactors in 28 different states, the nuclear industry is vital for many utilities and consumers throughout the country (U.S. Energy Information Administration 2022). These facilities were enough to generate approximately 778 terawatt-hours of emissions-free electricity in 2021 (Alves 2022). For reference, one terawatt-hour is equal to one trillion watts of electricity per hour. Nuclear electricity prevents approximately 471 million metric tons of carbon emissions into the atmosphere yearly (Nuclear Energy Institute 2022). Despite these impressive statistics, the nuclear industry in the U.S. has been declining for some time. Table I from the Nuclear Energy Institute demonstrates how the U.S. highly prioritized nuclear energy towards the end of the 20th century but has turned away from nuclear expansion since then.

From an overall production peak in 2012, 12 reactors have been retired with several more lined up for premature retirement in the coming years (Holt and Brown, 2021). According to the U.S. Nuclear Regulatory Commission (2022), there are currently 21 reactors around the country undergoing various stages of decommissioning, with a tremendous amount of clean energy being removed from the country's mix. Only two nuclear power reactors, Vogtle 3 and 4 in Georgia, are currently being constructed, and there are no current plans to build any other plants nationally. For comparison, China, notably the United States' largest competitor in the energy industry, has 22 domestic nuclear reactors under construc-

Table 1. History of U.S. Power Reactor Orders, Startups, and Shutdowns

Number of Reactors

Years	Orders	Cancellations	Startups	Shutdowns	Operating at end of decade
1950s	16	0	3	0	3
1960s	87	0	21	8	16
1970s	153	57	58	7	67
1980s	0	58	48	4	111
1990s	0	5	3	10	104
2000s	8	0	0	0	104
2010s	0	6	1	6	99
Total	**264**	**126**	**134**	**35**	

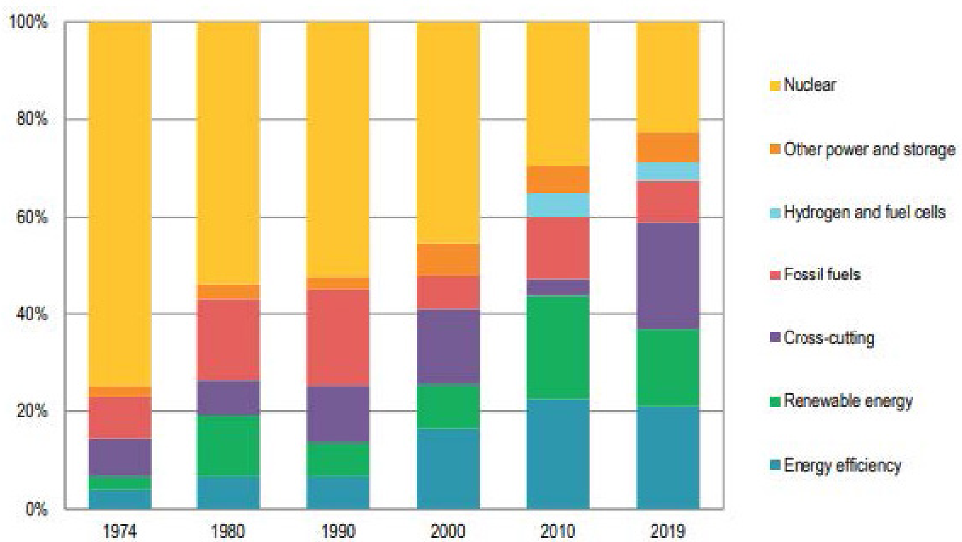
Source: Nuclear Energy Institute, Nuclear Regulatory Commission

Notes: 264 total orders minus 126 cancellations = 138 reactors that were not canceled. Of those 138, 4 are still under construction, leaving 134 that have started up. Of the 134 startups, 35 have shut down, leaving 99 currently operating. "2010s" are through November 2016.

tion, seeking to dramatically increase its clean energy production and nuclear innovation (World Nuclear Association 2022).

While nuclear energy has been established and deployed as a massive pillar of clean energy with vast potential to upgrade, other renewable energy sources continue to be prioritized in investment, development, and deployment throughout the country despite clear comparative underperformance and irregularity in generation. Millions of dollars in tax

Figure 1: Evolution of IEA Total Public Energy RD&D by Technology



Source: International Energy Agency

credits have been given to utility companies, private businesses, and households alike to build out the U.S.'s renewable energy infrastructure, with a specific focus on solar and wind power. Figure 1 from the International Energy Agency shows how the share of research and development funds dedicated to nuclear has plummeted over time, despite being the largest producer of clean energy during the time frame. Investments in renewable technologies have skyrocketed in recent years as well. In 2019, $59 billion was invested privately in renewable green technologies, more than a fivefold increase from 2005 (Jaganmohan 2021). For comparison, $7.5 billion is invested by private companies yearly for the upkeep and maintenance of our current nuclear fleet (Jaganmohan 2021). There is a clear disconnect here between private investments in renewable versus nuclear development, despite the essential nature of both to a clean energy transition. Public nuclear investment has also fallen by the wayside. This decline comes even though nuclear energy has extraordinary untapped potential for future energy production through innovations like nuclear fusion and portable reactors. However, this has begun to change following the passage of the Inflation Reduction Act of 2022, which was the largest public investment in clean energy in U.S. history. While this bill continues to prioritize renewable energy sources over nuclear power, there are still critical benefits for the industry that will be examined further later in the paper. These targeted investments in nuclear energy provide an excellent starting point for the continued support of nuclear energy into the future.

Despite extremely strong support amongst members of the government and the public alike, nuclear reactors throughout the country continue to face shutdowns, leaving gaps in necessary electricity production that are typically filled by fossil fuels (Ahn 2021). This unfortunate reality boils down to the economics and financing required to build, staff, and supply nuclear facilities before they can become profitable. Due to massive up-front capital costs, power plants often begin deeply in debt, making it rather difficult to emerge from construction and turn into a profitable venture. These costs will burden the project for the long term, and financiers and government budget hawks often look to pull the plug on these projects because of their expenses rather than wait for the unparalleled economic, social, and environmental benefits to be realized. Furthermore, the enduring beneficial externalities gained by the construction of a nuclear power plant, including emissions reduction, reduced risk of negative health effects, local job creation, and more, are not realized without project completion. While these up-front debts are not unique to nuclear power plants and are experienced by nearly every source of electrical generation, nuclear reactors face the highest up-front costs and a longer-term climb to profitability.

The biggest impact area of nuclear policy is climate change. As time continues without international cooperation and targeted investment in emissions mitigation, our planet's warming will continue accelerating. According to a 2022 Intergovernmental Panel on Climate Change (IPCC) report, our window of opportunity to prevent a 1.5°C permanent increase in global temperature is closing rapidly. Without a 45 percent decrease in greenhouse gas emissions globally by 2030, we are almost certain to eclipse a 1.5°C global temperature increase and continue down a destructive pathway for our planet (IPCC 2022). Without a key role for nuclear energy in the future energy mix, the future for life on Earth may be far more bleak than expected. The paramount considerations are how to continue generating carbon-free electricity affordably and how to build out infrastructure in enough time to make a measurable impact on climate change. This paper will analyze the financial and economic situations of the nuclear energy industry and examine two potential policy options that could establish the U.S. to act as a model to follow for other nations.

ECONOMIC COSTS AND BENEFITS OF CONVENTIONAL NUCLEAR ENERGY

FINANCIAL COSTS

As with any large-scale infrastructure project, there are a plethora of costs and considerations to take into account when designing and building nuclear facilities. As previously mentioned, constructing a large-scale nuclear power plant is not a cheap endeavor and may lead to consequences such as externalities. Externalities are defined as the effects of market activity on outside actors that are not incorporated into the costs borne by market actors. One example of an externality potentially posed by the construction of a nuclear facility is the removal of trees to clear land for the project, thus decreasing the amount of carbon absorbed from the surrounding atmosphere. The U.S. Energy Information Administration (EIA) estimates the cost of building a new commercial nuclear plant at $7,042/kW in 2022 dollars. This upfront investment has skyrocketed since the dawn of nuclear energy in the U.S., up from $2,485/kW in the 1960s, adjusted for inflation (World Nuclear Association 2022).

In recent decades, the proliferation of natural gas as a cleaner alternative to oil and coal has made the financial cost of producing electricity far lower and thus profitability comes quicker from these plants. Investor impatience, though rational in a free market, does not lead to the most beneficial outcomes for society. The same EIA study estimates that a natural gas plant costs $958/kW, a substantially lower cost than a nuclear power plant. Many utility companies have chosen to pursue this route to generate and provide electricity to their customers, despite the detrimental externalities they impose on the surrounding area and the environment (U.S. Energy Information Administration 2020). Not only are nuclear power plants expensive, but they are massive feats of engineering that encompass a large footprint of concrete and metal. The duration required to build these plants is extremely long, with a recent World Nuclear Industry Status Report (WNISR) estimating the average construction time to be upwards of 10 years, while natural gas plants usually take about two years (Schneider and Froggett 2021). If new conventional reactors were to be commissioned, these nuclear facilities may come online deep into the 2030s, which may be too late to make a significant impact on global warming mitigation. These long construction times will often lead to delays and exorbitant costs, sending projects far over budget before they can even begin operation.

As for the operating costs of a nuclear power plant, most spending goes towards the purchasing, handling, and disposal of uranium used to produce electricity (Schneider and Froggett 2021). While costs for generating electricity are rather low and have remained constant over the years, overhead costs for nuclear power plants, including salaries, have increased by more than 20 percent since 2002, approximately double the overhead costs of natural gas plants (Davis and Hausman 2016). While closing struggling commercial reactors may make financial sense for utility companies and investors seeking profitability, doing so typically transfers said monetary burden to consumers due to the massive decrease in electricity generation. If costs are high for financing nuclear energy facilities, the price of electricity charged to the consumer will inevitably rise to pay off debt. A case study on the closure of California's San Onofre Nuclear Generating Station in 2012 found that to meet demand, generating costs at natural gas plants grew by approximately $460 million in 2022 dollars and increased carbon emissions by 9 million tons in the first year alone (Davis and Hausman 2016). These externalities of nuclear closure added an estimated $869 million net cost to society through increased production costs, carbon emissions, further need for natural gas plants to meet demand, and more (Davis and Hausman 2016). Though maintaining nuclear facilities is not cheap, closing them is certainly not a cheap alternative either.

Realistically, when nuclear plants go offline, the only other option to make up for the lost energy generation would be fossil fuels such as natural gas plants, which are cheaper and quicker to build than any large-scale renewable alternatives. Generating the same amount of energy from renewables like wind and solar is practically impossible. The largest wind farms in the U.S. can have similar capacities for generation but require far more space to do so; wind farms require 360 times more land to produce the same amount of energy as one nuclear plant (U.S. Department of Energy 2018). These tradeoffs towards natural gas necessarily come with deleterious consequences to the surrounding ecosystem, health and safety of nearby residents, and the environment. Recent research concluded that nearly 8.7 million deaths globally could be directly attributed to the burning of fossil fuels, approximately 20 percent of all deaths recorded throughout the world (Vodra et. al 2021). Furthermore, the IPCC predicts a high to very high likelihood of marine, terrestrial, and freshwater biodiversity loss within the next 20 years without significant emissions mitigation (IPCC 2022). By retiring nuclear facilities without replacing them with other clean energy resources, we will all but ensure the scientific predictions regarding climate change will be realized, and potentially even exceed these predictions.

Another financial cost plants must consider is the safe, responsible handling and disposal of their nuclear waste. The vast majority of low-level nuclear waste can be safely disposed of above the ground surface or underwater, close to nuclear facilities and contained within sealed casks. Waste can also be repurposed into additional fuel, allowing for spent material to be converted into other fuels for more clean energy. This is currently not practiced in the U.S. but is done so widely in countries powered predominantly by nuclear power such as France (World Nuclear Association 2020). Furthermore, the area taken up by nuclear waste storage is incredibly miniscule compared to its energy output. If all the electricity used by one human in their entire lifetime was created by nuclear power, the associated nuclear waste would fit easily inside of a hockey puck (Hickman 2019). Since the dawn of nuclear technology in the U.S., the stored waste created to this date would take up about the size of one football field (Hickman 2019). All disposal processes are heavily regulated by several agencies of the U.S. government, including the Environmental Protection Agency (EPA), Department of Energy (DOE), and Department of Transportation (DOT), as well as independent, nongovernmental entities (U.S. Environmental Protection Agency). While the best options for long-term storage and use of nuclear waste is still up for debate, the current protocol for waste disposal is sound.

RISK COSTS

By far the most critical yet highly misunderstood economic cost is the risk of nuclear meltdown or catastrophe. Due to widely publicized disastrous incidents with long-term and wide-ranging consequences such as Chernobyl and Fukushima, the very real risks of nuclear energy are often overestimated and misinterpreted. Out of the hundreds of nuclear reactors that have been operational 24/7 since the advent of nuclear energy in the 1950s, there have only been three high-profile nuclear disasters in history: Three Mile Island, Chernobyl, and Fukushima. Of these three, Three Mile Island is the only one that has occurred in the United States, the country with the most reactors. This is a testament to not only to the efficacy of American ingenuity but also the profound safety measures that every plant takes every second of the day to prevent an emergency or failure. In fact, Chernobyl is the only nuclear disaster where any deaths from radiation can be directly attributed (World Nuclear Association). Another disaster of that magnitude could impose negative externalities upon a wide swath of land and population. However, when compared to the safety of every other electricity source and the amount of electricity each produces, nuclear proves to be the safest, with wind being the only alternative even close to nuclear's mark (MacKay 2009). Due to the toxicity of emissions and the danger of operations, especially in mining, thousands of deaths every year are directly caused by energy production from coal, oil, biomass, hydropower, and more (MacKay 2009). While dealing with radioactive material is inherently risky and poses the potential for calamity, the proper handling and operation of these plants has been demonstrated for decades. There is little to no risk posed by a nuclear power plant to the surrounding community, barring catastrophic mismanagement or an outside attack.

ECONOMIC BENEFITS

While the costs of nuclear power may seem problematic, they are outweighed by the economic and social benefits society receives from these power plants. This explains why they had been so successful and highly prioritized for U.S. electricity generation in previous decades. For starters, the generation of electricity from nuclear power creates no greenhouse gas emissions. This is a tremendous plus for the energy source and a factor that should put it at the forefront of the climate change debate and net-zero discussion. What sets nuclear apart from all other renewables or other clean energies is its capacity to continuously produce electricity. All nuclear plants in the U.S. supply power to approximately 73 million homes (U.S. Department of Energy 2018). Another benefit for nuclear power is its capacity factor, or ability to produce electricity at its maximum level. Nuclear power's capacity factor is approximately 93 percent, producing its highest possible energy output 93 percent of the time, with the rare geothermal energy being closest to matching this figure at 71 percent (Mueller 2020). The nearest scaled zero-emissions technology to nuclear's efficiency is hydroelectric power at 37 percent, a far cry from what nuclear power is capable of (Mueller 2020). Little to no fuel is being wasted in the process of fission, ensuring it is the most efficient fuel supply and energy output.

Nuclear's ability to produce energy is also independent of any external factors, such as weather or sunlight, which renewables like wind and solar are entirely reliant upon. Nuclear stations are also always on, generating throughout the day and night, except during periods of maintenance or refueling. When thinking about the economic implications of electricity, considering so much of our developed society today is conditional on electricity availability, nuclear facilities clearly provide the most reliable, steady, and enormous supply, with the crucial bonus of reducing our emissions overall. These factors not only apply to traditional stationary nuclear power plants but also to the future developments the world may produce with these technologies. An often-overlooked aspect of the tremendous energy production that is integral to a net-zero future is the ability of generated electricity to produce other clean fuels, such as hydrogen, on site (World Nuclear Association 2021). These capabilities will be invaluable to the clean transition of industries that are difficult to decarbonize, such as heavy-duty transportation and manufacturing. Innovation and advancement may unlock capabilities that were unfathomable to us at the beginning of the nuclear age, potentially setting nuclear up to dominate the world's future electricity generation.

Another strong argument for nuclear power lies in its ability to dramatically bolster local economies and provide hundreds of well-paying union jobs, standing as pillars of their communities. Jobs available in nuclear facilities run the gamut of abilities, qualifications, and backgrounds, with positions needing to be filled from atomic scientists and nuclear physicists to custodians, groundskeepers, and security. A 2012 Nuclear Energy Institute (NEI) report estimated that U.S. nuclear facilities employ over 100,000 workers each year, generating upwards of $50 billion in sales (Nuclear Energy Institute 2012). They employ a higher ratio of workers to electricity produced than all other energy sources, with an average wage of $31 per hour (Nuclear Energy Institute 2012). When compared to other clean energy sectors, nuclear reactor employees typically earn 25 to 30 and 33 percent higher wages than wind and solar workers, respectively (Watson and Ashton 2022). Additionally, nuclear energy provides 25 percent more careers per unit of energy produced compared to wind (Watson and Ashton 2022). For every dollar spent by these plants, they contribute "$1.04 in the local community, $1.18 in the state economy and $1.87 in the U.S. economy" (Nuclear Energy Institute 2012). Plus, on average, each plant will pay about $67 million in federal taxes and $16 million in local taxes (Painter and Muresianu 2021). These local and state revenues directly benefit the communities they are situated in, helping to fund other infrastructure projects such as road repairs. Furthermore, the economic impacts reverberate throughout the surrounding communities, with more money in the pockets of community members. Overall, these cornerstones of industry not only provide stable generation of electricity to millions of homes around the country, but also embolden state and local economies through tax revenue, electricity sales, and employment.

POLICY OPTIONS

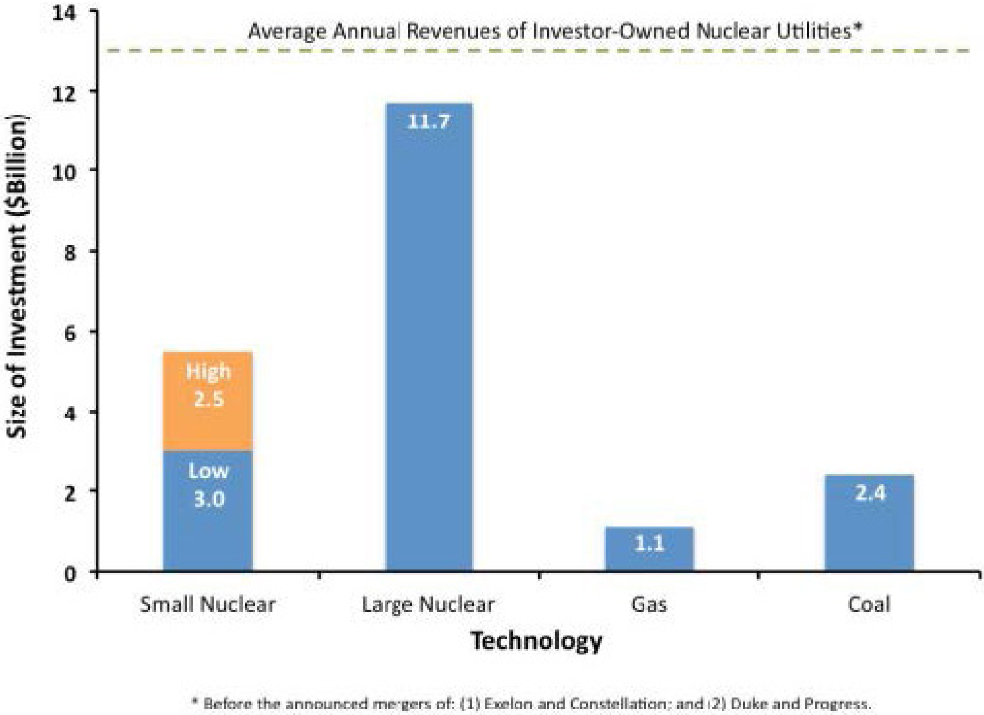
The economic benefits of nuclear energy to the country and the world are immense and multifaceted, though there are evident real-world trends in the wrong direction. As prices for construction materials and other commodities rise and the future of the global economy remains uncertain due to war and disease, the ability of nuclear energy to withstand these changes may diminish as time goes on. Furthermore, the impatience of private investors, such as large banks and corporations, has led to higher investment in fossil fuel energy to turn a quick profit. As such, nuclear facilities may not be able to survive in the long run simply due to the high prices of their construction and the burden of taxes, which the nuclear industry is not exempt from while the solar and wind industry receive plentiful investment credits. The government has a clear role to play in this scenario for the sake of its own domestic energy production capabilities and security, our global environment, and public health. Retiring current reactors early because of budgetary reasons undermines the commitment the U.S. has made to fighting climate change. This will handicap the largest source of clean energy currently available on the planet, driving the U.S. to become more reliant on fossil fuels or foreign energy sources. Not to mention, overall electricity demand is expected to continue growing rapidly into the 21st century, making supply and production even more critical. Therefore, the U.S. must consider a way to reduce costs to these plants to keep the nuclear industry competitive, whether through a subsidy of advanced nuclear construction or a generous production tax credit currently given to nearly all other clean energy sources.

FEDERAL SUBSIDIES FOR ADVANCED NUCLEAR CONSTRUCTION

First, and perhaps the best way to address this issue, is to partially or wholly subsidize the construction of new advanced nuclear facilities, specifically upcoming technologies such as small modular reactors (SMRs). A construction subsidy for such reactors would ease the significant financial burden that utility companies, states, and taxpayers bear. Similarly to the climate provisions in the Inflation Reduction Act and Infrastructure Investment and Jobs Act, Congress should pass legislation with significant funding to the Department of Energy expressly for advanced nuclear energy construction. This can allow for better prioritization of funds to focus on plant upkeep, high salaries, increased hiring, and more community events. This funding could be dispersed in large grants to state public utility companies or private nuclear development companies to facilitate investment. The reasoning behind choosing advanced nuclear over conventional nuclear is the shorter time horizon needed for completion and the cheaper up-front costs needed. For this paper, advanced nuclear energy is defined as nuclear energy technology exceeding Generation III, or conventional, nuclear technology. Nearly every reactor we know today in the United States is a conventional Generation III reactor; Generation IV reactors under development operate at higher temperatures, can produce greater amounts of energy and other fuels such as hydrogen, can take up less space, and incorporate technological advancements for efficiency and safety (World Nuclear Association 2020).

For instance, the only two commercial conventional reactors currently being built in the U.S., Vogtle 3 and 4 in Georgia, received large loans from the DOE totaling $12 billion. This financing is projected to save consumers approximately $600 million overall in costs that would have been passed on to them otherwise, showing how critical nuclear subsidies can be for reducing consumer costs (Georgia Power 2021). However, these loans need to be paid back over a long period with interest, which could put utilities like Georgia Power under tremendous financial stress over the long term. As an added positive externality, reducing the up-front cost of a nuclear plant can open utility company funds for investment in billions worth of other green technologies to bolster their renewable energy portfolio, such as wind and solar, to complement nuclear's zero-emissions generation and help fur-

Figure 2: Comparison of Size of investment (i.e. Overnight Cost) with Average Annual Revenues of Investor-Owned Nuclear Utilities



Source: International Energy Agency

ther drive down electricity costs. Thirty-six states mandate their utility companies to have a certain share of electricity generated from renewable sources, called Renewable Portfolio Standards (RPS), which have directly contributed to the tremendous growth of renewables since 2000 (Burbose 2021). As renewable requirements increase and RPS levels go up, it is entirely reasonable that utility companies could shift their investment focus on crucial renewable infrastructure if their financial burden on nuclear power was lessened. As Figure 2 suggests, nuclear plants once up and running are immensely profitable compared to fossil fuel plants, but realizing these gains is hindered by the lack of federal fiscal help.

These costs and the drawn-out planning and construction process for conventional reactors may be unfavorable to federal lawmakers, and thus subsidizing new technology like SMRs instead may be more cost effective and help bring future technology to the forefront of the energy market. These reactors are so small that they are easily transportable by rail or flatbed truck and are estimated to only take a few years from construction start to finish, compared to a decade or more for a traditional commercial reactor (NuScale Power 2022). An economic analysis done on NuScale, the U.S.'s first approved SMR, estimates the cost for their planned reactor in Idaho to cost approximately $2.47 billion in 2018 dollars, a paltry sum compared to a traditional reactor (Black and Paterson 2019). Despite this much lower cost and significantly smaller size, the facility still has a capacity of 685 MW, more than half of a traditional large-scale reactor (Black and Paterson 2019). It will be expected to add over 350 jobs at the plant and a total of $81 million annually in total economic productivity for the region (Black and Paterson 2019). Tax revenue from the construction alone is projected to add $143 million back into the federal government's pocket (Black and Paterson 2019). Similarly, the marginal operations costs of these smaller reactors including fuel and waste disposal are significantly less than that of a conventional water reactor. OPEN100, which provides blueprints for nuclear reactors, modeled a $3,064.79 capital cost per kilowatt-hour of electricity produced from a 115 MW small modular reactor, compared to a 1,114 MW reactor's capital cost of $5,503.44 per kilowatt-hour, adjusted for inflation (OPEN100 2020). However, SMRs are not exempt from these rising construction costs either; a recent NuScale report announced that the cost for their SMR has approximately doubled, almost entirely driven by a 75 percent increase in construction costs, underscoring the need for outside help (Schlissel 2023). As supply for these reactors grows with time, further technological advancement, and deployment, prices for SMRs are reasonably expected to decline and become even more affordable into the future, as has been the case with other clean energy technology such as renewables. Though the Idaho plant will not be online until 2026, it further underscores the importance of investing in more generating stations now and thus reaping the benefits from these projects sooner.

These projected statistics are merely one demonstration of why these nuclear technologies could be so vital to the U.S. economy. The small footprint of these plants allows them to be built nearly anywhere, allowing for physically small reactors to be installed near points of high demand to achieve large electricity generation. Furthermore, facilitating the development and deployment of these advanced nuclear projects can have profound effects on future production and deployment of other necessary clean energy tools, such as hydrogen created from nuclear energy. The Infrastructure Investment and Jobs Act included $8 billion in funding for 6 to 10 regional hydrogen hubs, industrial facilities where hydrogen, a clean fuel for transportation and manufacturing, is produced at scale with no emissions (U.S. Department of Energy 2022). It is stipulated by the DOE that one of these facilities must be nuclear powered to produce clean hydrogen, emphasizing the Biden Administration's commitment to the continued development of advanced nuclear and its commercial applications (U.S. Department of Energy 2022).

However, these reactors are not a panacea for the nuclear industry and come with their own drawbacks and hurdles. Due to the technology being very new relative to other nuclear alternatives, it is still up for debate which designs are the most efficient, safe, and deployable at scale (Nuclear Energy Agency 2021). Certain components of these reactors are not necessarily analogous to traditional reactor components, meaning they have not yet withstood the decades of testing and demonstration rigor that the rest of the nuclear industry has (Nuclear Energy Agency 2021). Without adequate investment in the research and development of these up-and-coming mechanics, public and private investment could be for naught if it is determined that certain designs do not stand up to regulatory or safety standards. Another potential concern to widespread deployment is perception of SMRs, which are not well understood among the general public. Even though these technologies would likely considerably decrease costs of electricity and lower risks of adverse health outcomes for nearby residents without a substantial risk to their safety, there could be potential backlash to a reactor being placed in population centers (Nuclear Energy Agency 2021). Though these are potential challenges to advancements in clean energy production, similar challenges have faced many new technologies and can be overcome with proper demonstration, testing, public education, and government support.

Considering the $12 billion loan for Georgia's Vogtle 3 and 4 reactors, this amount could easily finance three to four SMRs in differing areas of the country, targeting where supply and demand imbalances are most pressing and where air quality from electricity generation is the worst. This construction subsidy option has wide-ranging positive externalities including cleaner air in areas surrounding these plants, especially if they replace electricity generated from fossil fuels, and lower costs for drivers of electric and hydrogen vehicles. Opportunities like these give the United States a clear pathway to bolster domestic and global energy innovation, one that it would be foolish not to capitalize on as climate change accelerates.

ENHANCED FEDERAL PRODUCTION TAX CREDIT

Offering a tax credit for the production of nuclear power is another potential solution to relieve costs, though one that may not be as effective alone as a subsidy in the long run. A production tax credit (PTC) is defined as “a per kilowatt-hour (kWh) federal tax credit included under Section 45 of the U.S. tax code for electricity generated by qualified [clean] energy resources” (Environmental Protection Agency 2022). One of the economic benefits of nuclear power that is widely touted is the tax revenue it produces for federal and local governments. However, specifically regarding federal tax liability, this obligation can cut deeply into profits and is counterintuitive to the logic employed by the government to in-

Figure 3: Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020

Source: IRENA Renewable Cost Database

Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) of 7.5% for OECD countries and China in 2010, declining to 5% in 2020; and 10% in 2010 for the rest of the world, declining to 7.5% in 2020. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

centivize the proliferation of other clean energy technologies. The Inflation Reduction Act gave little priority to the nuclear industry in terms of investment considerations compared to renewable sources. Despite this, nuclear facilities did receive a power production tax credit, known as a 45U credit (Bipartisan Policy Center 2022). The credit, slated to begin in 2024, will provide “1.5 cents multiplied by kilowatt hours (kWh) of electricity produced minus 16% of the facility’s gross recipients in excess of 2.5 cents per kWh” (Bipartisan Policy Center 2022). This credit will sunset by 2032, when it becomes even more imperative for nuclear facilities to be generating clean electricity at high levels (Bipartisan Policy Center 2022). According to the DOE, this tax credit will save existing plants up to $15 per megawatt-hour. This could be a potential life-saving measure for some nuclear facilities, as the 2019 cost of generating electricity is more than double the credit at approximately $34, adjusted for inflation.

If the government is seeking to preserve the longevity of struggling reactors through a tax credit, the level would have to be raised considerably to make a real difference in their bottom lines. Perhaps one of the main contributors to the imbalance in growth between nuclear and renewables is the benefits received from their respective tax credits. According to the Tax Foundation, in 2018, renewable energy received $9.5 billion in credits compared to $100 million for nuclear. Increasing the production tax credit to upwards of half of production cost or in line with the credit-to-cost ratio of renewables could reduce the average $67 million federal tax burden each plant faces each year (Nuclear Energy Institute 2015). As the cost of generation fluctuates constantly due to supply and demand, a $15 tax credit today could make little difference if prices rise due to unforeseen circumstances. The amount of losses facing nuclear plants could be greatly slashed if so much did not have to be paid right back to the government. Most puzzling overall is that production tax credits for renewable energies such as biomass, solar, and wind have been in place as early as 1992 and have been successful at attracting investors, expanding access and installation, and decreasing costs (Mai et al. 2016). They have also been extended past their expiration dates several times since their implementation, showing how dedicated the federal government has been to the clean energy cause in the tax code (Sherlock 2020). These renewable tax credits, established as Section 45Y credits in the Inflation Reduction Act, are far more generous than the current nuclear tax credits primarily because of the much lower investment and operations costs for renewables. As referenced by the graph below (Figure 3), over the years 2010 to 2020, global generation costs for nearly every renewable energy source declined, with some declining notably, while nuclear generation costs increased (International Renewable Energy Association 2020). Implementing an appreciable increase in the nuclear production tax credit, scaled to the credit-to-cost ratio of the current renewable tax credits, could feasibly make nuclear more competitive with other clean energy sources growing at an exponential rate.

Nuclear reactor shutdowns are still considered prematurely without enough clean energy infrastructure in place to come close to filling the energy void left behind. Without the utilization of important policy tools such as tax incentives or subsidies, nuclear energy may fall by the wayside, unnecessarily becoming a relic of the past without any modern equivalent to take its place. Especially when utilized in conjunction, these two policies would not only build upon the current administration's programs to save nuclear energy but also allow for new sources of abundant clean energy to continue phasing out the fossil fuel plants that are detrimental to the wellbeing of our environment. Below is a tradeoff matrix of the four possible policy scenarios discussed in this paper: status quo, construction subsidy grants, production tax credit, or both. All outcomes besides the current status quo would be incredibly beneficial to the clean energy industry, local economies, urbanization and development, quality of life, and more.

CONCLUSION

While the nuclear energy industry is still a crucial component of our domestic electricity mix, soaring costs may inhibit service continuation or future investment. With the international political arena becoming increasingly unpredictable and volatile, ensuring an efficient and reliable energy supply is quickly becoming a predominant concern of national security. Around the world, 55 new nuclear reactors are being built with the majority concentrated in Asia, with many in China and India (World Nuclear Association 2022). The global prevalence of nuclear power shows how highly it is rated as a tremendous source of clean energy production around the world. In fact, due to energy crises throughout the world but specifically in Europe, several countries such as Germany are reversing their long-planned nuclear phaseouts to secure domestic energy production and independence. On a global stage, nearly every country in the world came together to agree upon the Paris Agreement, acknowledging that human actions have a profound effect on our planet's climate and that everyone has a role to play in combating global warming. Without extensive

Table 2: Tradeoff Matrix

Policy	Pros	Cons
0. Status Quo	• Save on present costs	• Continued premature plant shutdowns with fossil fuels replacing generation • Emissions increase, no emissions reductions goals achieved • U.S. loses position as leader in nuclear energy deployment and development
1. Construction Subsidy Grants	• Opportunities to get ahead in advanced nuclear deployment and generation • Reduction in emissions, inching closer to emissions targets • Collaboration on clean energy issues on international scale • Modernization of generation and grid • Job creation and economic benefits	• Increased government expenditures • Slightly increased risk to public from nuclear facilities
2. Production Tax Credit	• Opportunity to prolong life spans of nuclear facilities, saving clean energy generation and jobs • Could lead to reduction in costs as more nuclear facilities are built	• Decreased government revenue • Slightly increased risk to public from nuclear facilities
3. Construction Subsidy Grants and Production Tax Credit	• All aforementioned pros • Allows for the maximization of nuclear preservation and advancement	• All aforementioned cons

Source: Figure prepared by the author

and immediate help from the U.S. federal government, by the time 2050 comes, it may be far too late to reverse climate change.

Though the current range of options available to nuclear power is underwhelming, help seems to be on the horizon. Several crucial bills for the industry sponsored by members of both parties in both chambers of Congress have the potential to reverse the downward path the industry has been on. Furthermore, the Biden Administration has made saving and developing nuclear power a crux of its environmental policy, a welcome sign for the U.S.'s ability to lead on fighting climate change domestically and internationally. Funding for research and development into advanced nuclear capabilities, including fusion and hydrogen production, has grown in recent years and breakthrough discoveries could lead to deployment in the not too distant future (World Nuclear Association 2021). While a nuclear revitalization is possible, it will not come to fruition unless nuclear subsidies or tax credits in conjunction remain a top priority for policymakers.

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