Diversifying Nuclear Power Technology: A Technical Analysis on Small Modular Reactors and Their Impact on Nuclear Energy Policy

Carolina Lizbeth Lugo Mejia and Marcos Lugo

Carolina Lizbeth Lugo Mejia
Carolina is currently pursuing her master's degree in public policy at Liberty University. Previously, she obtained her bachelor's degree in mechanical engineering with a nuclear track. Her interest in is in contributing to the contemporary energy and environmental challenges of our time with some emphasis on nuclear energy based on her background. She expects to compile her knowledge of both technical and policy aspects of nuclear energy to provide viable solutions that promote the benefits of the energy source.

Marcos Lugo
Dr. Marcos Lugo is a mechanical engineering professor at Liberty University. He has ample experience in both academia and industrial research. He obtained his Ph.D. degree from Mississippi State University with a specialization in fatigue analysis focused on innovating manufacturing processes for materials. His work can be applied to various aspects of the automobile, aerospace, and biomedical industries. However, this paper represents his interest in expanding and applying his research to nuclear technology.

Introduction

The energy policy debate in the United States has revolved around the diversification of energy sources while promoting advantageous economic profits. One drive for this has been the discussion of anthropogenic, environmental endangerment concerns (Vlassopoulous 2011, 104). However, despite the environmental concerns, the U.S. has for some time only relied on one type of energy source—fossil fuels. Fossil fuels are categorized as natural gas, coal, petroleum, and other gases responsible (U.S. Energy Administration 2019). Natural gas is responsible for 38.4%, coal for 23.4%, petroleum for 0.4%, and other gases for 0.3% of the U.S.'s electrical generation (U.S. Energy Administration 2019). Although, many solutions specifically those proposing renewable energy have been proposed, an energy source that has remained stagnant in technological development is nuclear energy (Vegel and Quinn 2017, 395). Nuclear energy currently accounts for 19.6% of the electrical generation in the US, and efforts of decarbonization and diversification would be greatly aided by nuclear energy development (Lester 2016, 45). Nuclear energy is the only source of energy that does not emit carbon dioxide to the atmosphere: Averages of carbon dioxide emissions for oil, coal and gas during their total life cycle are 778, 960, and 443 gCO_2e/kWh respectively (Sovacool 2008, 2956-2960). A nuclear power plant emits 66 gCO_2e/kWh on average during its life cycle, mainly because its reliant on fossil fuels for different stages of plant construction and processes like the mining and enrichment of uranium (Sovacool 2008, 2956-2960).

However, if the United States aims towards higher dependence on nuclear energy, the various issues hindering nuclear energy development must be addressed first. Most reactors contributing to the 19.4% electrical generation in the country were developed in beginning of the atomic age (Morgan, et al. 2018, 7185). Currently, the United States has 58 fully operational commercial nuclear power plants (U.S. Energy Administration 2019). However, 11 power plants with a combined capacity of 18,000 MW are expected to be shut down by 2025 (Lesser 2019, 13). If decommissioned, this would mean a loss of 18% of the country's total nuclear capacity (Lesser 2019, 14). This is a recurring theme in the nuclear industry, as a lot of nuclear power plants are aging, and new ones have proven to be a financial burden and very difficult to build (Morgan, et al. 2018, 7185). Furthermore, 35% of the nation's nuclear fleet is at risk of retirement, which could imply a 4-6% increase in carbon emissions by 2035, if these nuclear power plants were to shut down (Morehouse 2019). These issues can be separated in the need for further nuclear technology development, which would be resolved by programs led by the DOE. The decommissioning aspect, however, falls under the purview of the Nuclear Regulatory Commission (NRC) (Saling and Fentiman 2001, 354). Thus, the nation is facing the decision of decommissioning some nuclear power plants or resolving the issue of running them for 60 to 80 years without compromising the structural integrity of nuclear reactor components (Morgan, et al. 2018, 7185). While running power plants for longer without compromising structural components that could potentially be dangerous is a viable solution that should be explored, there are other alternatives currently under research. One of the most attractive solutions currently are small modular reactors (SMR(s)), which seem to be attractive for the size reduction and possible economic advantages that are entailed to their design (Vegel and Quinn 2017, 395). However, if the United States aims towards higher dependence on nuclear energy, the various issues hindering nuclear energy development must be addressed first. Thus an overview of the necessity of diversifying the energy industry with an emphasis on nuclear energy is key to determining the future of nuclear energy in the United

States An outlook of how nuclear energy policy has evolved, the attractiveness of embracing SMR designs, and licensing and regulatory processes will be presented.

Nuclear Technology Design Evolution

To understand the necessity for novel technological developments, it is first important to have a basic understanding of how reactors work. Generally, a nuclear reactor is a device used to produce energy in the form of heat: The heat generated by a reactor in turn is used to produce steam, and then to generate electricity (Lamarsh and Baratta 2001). A reactor usually consists of a reactor core in which the nuclear reaction occurs, a working fluid (usually water) utilized to remove heat from the reactor core, a reactor vessel to prevent the reactor from emitting radiation and neutrons, and a containment structure to prevent from radiative leakage (Lamarsh and Baratta 2001). Several types of nuclear reactors exist to date; usually, they are classified depending on specific features or the scale size. The most popular small, medium, and large reactors currently are the fast-breeder reactor (FBR), light-water reactor (LWR), and boiling-water reactors (BWR) respectively (Lamarsh and Baratta 2001).

A nuclear reactor is made up of several components such as the fuel, moderator, control rods, coolant, pressure vessel, steam generator, and containment among others (Knief 2014, 10-20).These elements can vary depending on the specific type of nuclear reactor. Thus, nuclear reactors are classified according to the different fuels, moderators, control systems, cooling system, configuration, etc., in the reactor. As the core reactor functions at higher temperature the more efficient in generating electricity (Patterson 1986, 26). With the intent of illustrating, a pressurized water reactor (PWR) will be described with more detail here to establish some of the improvements and advancements in the design of nuclear reactors. A PWR is a welded large structure made of steel. The vessel contains the reactor core, which is made up of the fuel elements and the control rods, and the remaining space in the vessel is filled out of pressurized water. The fuel elements consist of tubes made of zircaloy filled with uranium pellets (Patterson 1986, 40). The water in the pressure vessel has several functions—moderator, reflector, and coolant (Patterson 1986, 40). This water must be subjected to high pressure to prevent from boiling.

Design Considerations Through the Years

Over the years the design of a nuclear reactor has evolved to provide more reduced design and more efficient systems. The evolution of the design of nuclear reactor has been classified by generations: *Generation I*, *II*, *III, and IV*, the latter being the current state of the art for nuclear reactors. *Generation I* refers to the first prototypes and power reactors that launched between 1950s and 1960s (Locatelli, Mancini and Todeschini 2013, 1503). This generation included water and gas cooled reactors (Goldberg and Rosner 2011, 3-7) (Locatelli, Mancini and Todeschini 2013, 1503). Essentially, these reactors demonstrated the feasibility of operating a nuclear system. In this stage large PWRs, BWRs were developed in U.S and the CANDU (acronym for CANada Deuterium Uranium) in Canada to mention other reactors (Kerlin and Upadhyaya 2019, 6).

Generation II is a class of large commercial reactors that were designed to be economically competitive with an expected life of 40 years. These types of a reactors included PWRs, BWRs, and they were classified as light water reactors (LWR), and advanced gas-cooled reactor (AGR) (Kerlin and Upadhyaya 2019, 6). In the U.S. the PWRs and BWRS were more popular which use light water, in contrast with others like the CANDU that use heavy water (Kerlin and Upadhyaya 2019, 6). This generation incorporated automated safety features that involved electrical or mechanical operations (Kerlin and Upadhyaya 2019, 6). Construction of these reactors in the U.S. and other countries took place between the 1960s until the 1990s (Kerlin and Upadhyaya 2019, 6). A key technical aspect of these nuclear reactors is that they require large electrical grids, and require of a special waste repository for the large quantities of used fuel (Kerlin and Upadhyaya 2019, 6) (Goldberg and Rosner 2011, 4).

Nuclear reactors of *Generation III* are characterized by significant improvements made to the designs from *Generation II*. Among the improvements made were standardized and simpler designs, passive safety features, longer refueling time, improved thermal efficiency, and longer operational life (average 60 years) (Kerlin and Upadhyaya 2019, 13). A standardized design allows for a reduction in capital investment and construction time, and to reduce maintenance. The introduction of passive safety features avoids the need of active controls. There are four *Generation III* reactors currently operating in the world but none in the U.S., and all of them are ABWRs (Kerlin and Upadhyaya 2019, 13) (Goldberg and Rosner 2011, 6-7).

The last generation of nuclear reactors are under development: *Generation IV*. *Generation III* made an emphasis on improving designs and addressing safety requirements. *Generation IV*, however, is expected to provide significant advances in safety, financial competitiveness, reliability, and environmental aspects to make it a provider of clean and electricity and sustainable energy industry (Rosner and Goldberg 2011, 14). The reactors of this generation will include advances in safety and reliability and an enhanced investment protection for plant owners. A strategy being implemented to diminish financial risk is to improve the efficiency of the electricity generation systems, modular construction, and shortened development of the whole process (Nakhabov and Ud-Din Khan 2020, 214-219) (Goldberg and Rosner 2011, 14-15) (Goldberg and Rosner 2011, 14). This generation of nuclear is addressing various innovative concepts designs to compete economically, all of them operate at high temperature, and therefore, offer a better efficiency. *Generation IV* make better use of passive safety systems and better use of uranium resources.

The Small Modular Reactor

The development of nuclear reactors has been classified as *Generation I*, *II*, *III*, and *IV* with *Generation IV* being the most recent advanced reactors. Due to the advances incorporated currently on the SMRs, they are positioned in *Generation IV*. Small nuclear reactors are not new; in fact, Westinghouse designed a commercial small reactor by 1958 but them have evolved over the years (Ingersoll and Carelli 2014). To date, the same features that are found in large and conventional nuclear reactors are found also in these SMRs. SMRs are currently of interest because they are able to overcome some of the barriers that have been prevented large scale reactors from future development (Mignacca, Locatelli and Sainati 2020, 118-137) (El-Genk and Palomino 2019, 181-198). As expected, one of main factors is to assure financial success to investors. Currently, SMR technology is promising with several designs at the stages of development, construction, or in the licensing stage (Mignacca, Locatelli and Sainati 2020, 118-137) (El-Genk and Palomino 2019, 181-198).

A small modular reactor produces an output power of 300 MWe in average and comprises features of LWRs and other types of reactors (Vegel and Quinn 2017, 395). Small Modular Reactors are smaller than the gigawatt large nuclear reactors operating at present. The modularity design concept offers the opportunity to integrate several modules on the same location and to improve the manufacturing process by introducing standardized components (Cooper 2014, 163). These components are manufactured in significant amounts and can be assembled on site and transported assembled units, thus simplifying the control costs and lowering costs (Cooper 2014, 163). Modularity also refers to the unit of the nuclear steam supply system (NSSS) which is connected to the process heat supply system (Ingersoll and Carelli 2015, 4-6). Furthermore, the modularity concept used for the design of SMRs allows construction of most components in a factory, then, they are transported and assembled on the location site of the nuclear plant. As a result, modularity brings the advantage of a shorter construction period and lower construction costs. Along with this, a reduction in costs of installation and the routinely functioning of the reactor (Cooper 2014, 163).

Safety is paramount when designing a nuclear reactor. Designers of SMRs are confident that the design of SMR is safer than conventional reactors (Lokhov and Sozoniuk 2016). While the design of a SMR essentially contains similar elements as a large reactor such as fuel type, cooling method, etc., a SMR possess significant enhancements that made them safer (Locatelli, Bingham and Mancini, Small Modular Reactors: A Comprehensive Overview of Their Economics and Strategic Aspects 2014, 75-85). Passive systems that minimize human intervention in unexpected situations is one of the additions that have been incorporated to SMRs. Integral design concept is another feature that has been implemented, which means that all the principal components of the reactor are located in only one pressure vessel (Locatelli, Bingham and Mancini, Small Modular Reactors: A Comprehensive Overview of Their Economics and Strategic Aspects 2014, 75-85) (Rosner and Goldberg 2011). Thus, combining all these characteristics, SMRs present a viable solution that could provide various technological, safety, and economical resolutions to the current barriers presented in other nuclear technology.

Economic Overview of SMRs

The size of a SMR has been considered as a drawback when evaluating the viability of a SMR versus a large reactor (LR(s)) because of scale economies: the argument is that SMRs' size reduction would enable the installment of multiple reactors in one location; however, this may also incur additional costs that would be exceed those of installing one large reactor, thus not providing a significant advantage (Locatelli, Bingham and Mancini 2014, 76). Nevertheless, the size is only one factor to consider in the evaluation of a SMR. But the commercial success of the SMRs will rely greatly on the economic viability. Even though scale economies are a highly important factor there are more to consider in the economic analysis of SMRs. Table 1 illustrates other factors that can be used to compare SMRs to large reactors (LRs) (Carelli, et al. 2010, 404).

Table 1. List of factors in the Evaluation of Competitiveness Between SMRs vs LRs

SMR Ad Hoc (Specific) Factors	Common factors
Design-related characteristics	Size
Compactness	Modularization
Cogeneration	Factory fabrication
Match of supply to demand	Multiple units at a single site

Reduction in planning margin	Learning
Grid stability	Construction time
Economy of replication	Required front end investment
Bulk ordering	Progressive construction/operation of multiple modules
Serial fabrication of components	

Source: (Carelli, et al. 2010, 404)

The costs of a nuclear plant are divided into capital costs, operating and maintenance costs, fuel, and decommissioning. The indicator that used by policy makers is the Levelized Cost of Electricity (LCOE) and expressed in ($/KWh). This indicator accounts for all the incurred costs through cycle life of the plant (Locatelli, Bingham and Mancini, Small Modular Reactors: A Comprehensive Overview of Their Economics and Strategic Aspects 2014, 78). Usually, in the economic analysis of nuclear power plants two popular methods are used—Net Present Value (NPV) and Internal Rate Return (IRR). The first method gives as a result an amount of ($) that is affected by various economic indexes. The second method provides a dimensionless indicator or percentage, the higher percentage represents the better option. However, the Levelized Cost of Electricity (LCOE) seems to be the index used for making decisions at present, especially because the viability of nuclear energy is compared to the other competitors: coal-based energy and gas-based energy.

The use of different assumptions, and perhaps misinterpretations, of some parameters used in some calculations of the LCOE have provided different values for the LCOE indicator. Nonetheless, the values obtained from the literature could be used as the basis to make decisions. Investigations made by the Massachusetts Institute of Technology (MIT) seem to be the base for several analysis found in the literature. The three most important alternatives for the generation of electricity are given in Table 2 (Parsons and Joskow 2009) (Mari 2014, 156).

Table 2. Cost of Electric Alternatives

	Overnight Cost $/kW	**Fuel cost $/MMBtu**	**Levelized Cost of Electricity, ¢/kWh**
Nuclear	4,000	0.67	8.4
Coal (low)	2,300	1.60	5.2
Coal (moderate)	2,300	2.60	6.2
Coal (high)	2,300	3.60	7.2
Gas (low)	850	4.00	4.2
Gas (moderate)	850	7.00	6.5

Gas (high)	850	10.00	8.7

Source: (Parsons and Joskow 2009, 52)

Table 2 includes several scenarios for the coal-based and gas-based production, where low refers to the minimum price for the energy production. As seen in the table with these numbers, when averaging the values, nuclear energy is third place in economic competitiveness, but very close to the gas alternative. The overnight cost of $4000/kW has been a motive of criticism, perhaps due to a miscalculation or an overestimation of this value (Mari 2014, 155). In addition, some may have placed a lot emphasis on this cost.

As stated in the beginning the SMRs have motivated a lot of research and have been placed as an attractive candidate when discussing the use of nuclear energy. When the decision is nuclear energy the question that arises is if a SMR could compete against a LR. Economies of scale is a factor that has been argued to be fundamental in the decision of SMR against LR. However, Table 3 illustrates several factors comparing a large reactor of 1340 MWe and a set of 4 SMRs of 335 MWe. As can be seen the gap between a large size reactor and the set is just 5%.

Table 3 Comparison of Major Factors Affecting Capital Costs in SMRs and Large Plants.

Factor	**SMR/large capital cost factor ratio**	
	Individual	Cumulative
(1) Economy of scale	1.7	1.7
(2) Multiple units	0.86	1.46
(3) Learning	0.92	1.34
(4) (5) Construction schedule and timing	0.94	1.26
(6) Design specific	0.83	1.05

Source: (Ingersoll and Carelli 2014, 71)

Licensing and Regulatory Processes

Nuclear energy policy in the United States is regulated by the following agencies: The Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), and the Department of Transportation (DOT). The NRC is responsible for assessing and issuing licenses for waste handling and processing, transportation, and disposal activities (Saling and Fentiman 2001, 19). All commercial nuclear reactors and fuel-cycle facilities must be licensed by the NRC as well as some other state and local agencies to be operational (Knief 2014, 487-498). The NRC was also responsible for creating and stipulating the concept of ALARA (As Low As Reasonably Achievable), which refers to the levels of radiation exposure conditions that must be implemented for the security of nuclear power plant workers (Saling and Fentiman 2001, 44) . The NRC must first issue a design certification for each new reactor (U.S. NRC 2020) . A design certification comprises of what the NRC has labeled as its *rulemaking process* as well as a staff's review of the application (U.S. NRC 2020). The *rulemaking process* refers to rules that the NRC might impose on licensees to obtain or maintain a certification; the rules may include restrictions and regulation pertaining to the use of hazardous or nuclear materials that are used in power plants, research reactors, uranium mills, fuel facilities, and waste disposal facilities (U.S. NRC 2020). Once the certification is obtained, it is valid for 15 years, and it can be renewed for up to 10-15 years (U.S. NRC 2020) . However, this is only a certification for a reactor design; the next step in the process would be to obtain a combined license, which enables the licensee to construct and operate a nuclear power plant in an approved site (U.S. NRC 2020).

NuScale SMR Design Approval Implications

A new development in this category that deserves a special mention is the NuScale reactor. The capacity of the rector is in the order of 45MWe. The concept design is based on the multi-application small light water reactor (MASLWR). This reactor was born in U.S. financed by the department of Energy (DOE) and the Idaho National Laboratory. This concept has been licensed foe commercialization (D. T. Ingersoll 2009, 596) (D.T. Ingersoll 2014, 84-85). The engineering nuclear technology used is the same as for the SMR concept, except this one is very compact allowing up to 12 moduli to be located in the same pool of water. Among the features of this reactor that can be mention are compact size, natural circulation cooling, light water reactor technology, and nuclear modularity. Another feature is that this concept allows dedicated power trains. It is, each module is independent of other modules, and thus, the nuclear plant can be operated according to the energy needs (D.T. Ingersoll 2014, 84-85).

The impact of the NRC's recent license approval of NuScale Power's SMR design can encompass various aspects of the nuclear energy industry. For instance, once this design receives its full certification (Expected date: August of 2021), utilities will be able to reference this decision when applying for combined licenses to operate new reactors in the United States (Office of Nuclear Energy 2020). It is also important to note that the application took less than 42 months to review, which would be faster than it has been done in the past (Office of Nuclear Energy 2020). This a key factor to note as it goes on to prove that lengthy licensing process could deter further development in the actual technology. As was specified before, design certifications are different from combined license applications; therefore, this would imply that the actual construction of the reactor is still not approved. Nevertheless, NuScale Power's SMR design is about a third of the size of a large-scale reactor, and its design allows for the reactor to cool itself without the need for additional water, power, or operator action; this could lead a significant reduction in the emergency planning zone which would then lead to a reduction in footprint by the nuclear power plant (Office of Nuclear Energy 2020). Finally, SMR designs present the possibility of comparatively better economic proposition in the nuclear energy industry (Office of Nuclear Energy 2020).

Public Perception of Nuclear Energy and Its Impacts on Nuclear Energy Policy

In the 1950s, the concern was to shift the image of nuclear energy from being a tool for weaponization towards emphasizing alternative uses, and in a sense served as a major goal in a political agenda (Beaver 2010, 536). However, this type of perspective enabled a lack of foresight in nuclear energy policy regarding financial and waste management risks that would become an apparent barrier for nuclear technology in the future (Beaver 2010, 536). Reiterating that one of the main reasons behind recent advocacy for nuclear energy is related to climate change concerns; bipartisan support is varied. While 77% of Americans believe that the government should reinforce efforts to introduce alternative ways of generating electricity, 90% of Democrats prioritize utilization of cleaner sources to 67% Republicans who share the same views (Funk and Hefferon

2019). Some Republicans even advocate the expansion of fossil fuel development (Funk and Hefferon 2019). However, these statistics pertain to renewable energy in comparison to fossil fuels, which has set the tone for energy policy in America. The United States population seems to be more in favor of further developing alternative energy sources but is not necessarily advocating for nuclear energy.

While the discussion above deals with a general, partisan overview of energy policy, nuclear energy policy is deeply affected by public perception. One of the contributing factors influencing the public on nuclear energy can be found in the media depiction of nuclear energy. Insight into the nuclear energy depiction phenomenon can be found in an analysis of the most noted nuclear accidents: Three Mile Island, Chernobyl, and Fukushima. Among the similarities in the coverage of the three accidents, it was found that a lot of the mainstream reports on all three accidents lacked sufficient knowledge on nuclear science and radiation to make informed reports on the events; reporters who were more informed formed part of the minority (Friedman 2011, 57) (Friedman 2011, 57). Along with the lack of expertise on the field, another problem that various reporters experienced was the ability to discern their expert sources (Friedman 2011, 63). The combination of these two factors enabled the creation of unreliable news that, unfortunately, reached the larger public; for instance, only a few months after the Fukushima incident, the terms "Fukushima and radiation" produced 22,400,000 search results in Google (Friedman 2011, 60). The problem when there is a plethora of information is that it becomes increasingly difficult for news sources, more accessible to the public, to discern the quality and reliability of the information presented (Friedman 2011, 62).

Involvement of this nature is key in any policy issue; however, in this case the negative perception towards nuclear energy could potentially hinder the growth in nuclear technology development. For instance, both the certification and combined license application processes, include public meetings as a part of the application review (U.S. NRC 2020). A typical *rulemaking process*, used for the design certification of reactors, includes a platform for stakeholders considering input from the public; the Advance Notice of Proposed Rulemaking (ANPR) conducts several meetings where public comments are discussed and accounted for in potential rule expectations for aspiring or continuing licensees (U.S. NRC 2020). Thus, if participation from the public is playing a key role in the licensing aspect, it could potentially imply delays in construction of both reactors and power plants. Then, if favorable public opinion is to be obtained, policy makers in advocacy of nuclear technology development should make an effort to inform the public on the various advantageous characteristics of diversifying and amplifying the usage of nuclear energy.

Development Setbacks

The Department of Energy (DOE) has an office dedicated towards the advancement of nuclear technology named the Office of Nuclear Energy (NE). The Office of Nuclear Energy focuses on research to advance and ensure security in nuclear technology. Its main objectives are to maintain the sustainability and competitiveness of existing nuclear U.S. fleet, create advanced reactor pipelines, and ensure and execute tactical fuel cycle and supply chain infrastructure (Office of Nuclear Energy 2020). As they are an agency with a focus on research, the DOE oversees some national laboratories and government-owned research facilities (Knief 2014, 476). Among one of its main functions is also the responsibility of oversight for waste management. Under the Nuclear Waste Policy Act of 1982 (NWPA), the DOE was held responsible for providing federal interim storage of spent nuclear fuel (SNF) and providing a plan for a permanent geological repository for commercial nuclear power plants (Saling and Fentiman 2001, 78). According to the Office of Nuclear Energy, some of the highlights for the fiscal year 2019 budget were:

- $128M for R&D on advanced reactors, including
- $54M for advanced Small Modular Reactors R&D
- $15M for versatile advanced fast test reactor R&D
- $40M for accident tolerant fuels
- $47M for crosscutting competitive cost-shared R&D
- $34M for Nuclear Energy Advanced Modeling Simulation to incorporate HUB capabilities
- $340M Idaho National Laboratory infrastructure and S&S
- $10M for used nuclear fuel disposition R&D

However, the issue with nuclear technology development deals with the advancement emphasis and distribution of resources (Morgan et al. 2018, 7185). The Department of Energy Office of Nuclear Energy (NE) is responsible for the development of non-light water reactors, an effort that has been ongoing since the late 1990s, cost about $2 billion dollars, and has shown very little progress since that time (Morgan, et al. 2018, 7185). The distribution of resources is perhaps the defining issue with nuclear technology, the NE funds vary fourfold, thus, certain projects are prioritized, not necessarily because of their technological and economic benefits, but rather because of institutional favoritism (Morgan, et al. 2018, 7185). The NuScale SMR design approval represented an economic push of more than $400 million by the DOE since 2014 (Office of Nuclear Energy 2020). Thus, while the decision represents a milestone and can serve as precedent for improvement in nuclear technology, it also illustrates the economic burden that must be made to support nuclear technology development.

Conclusions

Nuclear technological development in the United States has been stagnant due to the aging technology. Lengthy and meticulous regulatory processes have also played a factor in slowing down development of nuclear technology. Nevertheless, nuclear energy still provides sufficient reliable characteristics that make it an attractive competitor in an evolving energy industry. However, further development of nuclear technology must be explored and emphasized in efforts to diversify the industry. As for perceptions toward the energy source, advocates of nuclear energy should strive to inform the public on the advantages of increasing dependency on nuclear in an accessible way to replace fear and misinformation with trust. Furthermore, agencies in charge of research development and regulatory restrictions should attempt to prioritize the projects that offer the greatest viable solution to the industry and address deterring factors in regulatory processes.

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