THE FUTURE OF SMALL MODULAR NUCLEAR REACTORS IN THE U.S.

STRATA

October 2017

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Introduction

Small Modular Nuclear Reactors (SMR) have the potential to transform the nuclear energy industry in the US and across the world. SMR technology rejects the conventional wisdom of economies of scale in favor of a design and manufacturing environment that standardizes component production. These components are fabricated and assembled in factories to make reactor modules which can take advantage of process efficiency.

Small reactors are not a new idea. During the first decade of nuclear energy production, 14 reactors were built with a generating capacity of less than 100 MWe (megawatt electric). The move to larger reactors began shortly after that, however, as builders began to realize they could double a plant's power output with less than double the building supplies. This realization quickly gained momentum. Less than 15 years after the first small nuclear reactor began producing electricity, plants with outputs of 800, 900, and 1,000 MWe were coming online.[1]

According to the US Energy Information Administration (EIA), a 1,000 MWe nuclear reactor produces enough energy to power nearly 750,000 homes.[2] Out of the 99 nuclear reactors currently operating in the United States, 88 have capacities of 800 MWe or more.[3] The largest reactor in operation in the US is the 1,500 MWe Grand Gulf reactor in Mississippi.[4] In contrast, SMRs have a generating capacity of less than 300 MWe. The smaller, modular nature of this technology offers potential solutions to many issues that have plagued larger nuclear facilities. SMRs provide the same carbon-free, efficient, and reliable electricity production as larger reactors, but require less up-front capital investment, offer more advanced safety features, and are more easily adapted to fit electricity customers' needs.

Modern SMRs differ from early small reactor designs. They utilize advanced reactor technology and rely on the modular nature of the design to provide advantages over typical large nuclear reactors, where the majority of fabrication occurs on-site. These designs began to gain traction in the early 2000's thanks to funding initiatives from the Department of Energy.[5] Private funding has also played an important role in SMR development, but federal support remains a major boon for SMR projects.

As with any new technology that must comply with regulatory standards, SMR technology faces a number of barriers to its adoption. This paper attempts to analyze many of the significant barriers impeding SMR technology in the US with a focus on the impact of regulation. We first give an overview of the benefits and potential of SMR technology, then we provide a discussion of barriers to adopting SMR technology in the energy industry and give policy recommendations to help reduce those barriers.

SMR Technology Potential

SMR technology presents an exciting opportunity for the future of energy production in the US and has the potential to play a major role in the US energy portfolio. Nuclear power currently makes up about 20 percent of US electricity generation. That number, however, will drop in coming years as old nuclear reactors are retired. The EIA predicts that by 2050, nuclear power will account for about 11 percent of total electricity production in the US. Those

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1 Power Reactor Information System. (2017, August 8). *Country Statistics: United States of America*. Retrieved from https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US

2 A 1,000 MWe nuclear reactor will produce 1,000 MW of electricity every hour if it is operating at full capacity. However, typical nuclear power plants operate at between 90 and 93% of their full capacity. The estimate used here is based on the average annual electricity consumption and the national average nuclear capacity factor reported in 2015. U.S. Energy Information Administration. (2016, October 18). *How much electricity does an American home use?* Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=97&t=3; U.S. Energy Information Administration. (2017, August 24). *Electric Power Monthly*. Retrieved from https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b

3 Power Reactor Information System. (2017, August 8). *Country Statistics: United States of America*. Retrieved from https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US

4 *Ibid*.

5 World Nuclear Association. (July 2017). *Small Nuclear Power Reactors*. Retrieved from http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

numbers reflect expected retirements of old nuclear plants, increased competition from alternative energy sources, and expected growth in US electricity demand of up to 92 percent over the same period.[6]

Traditional operating licenses for nuclear reactors issued by the NRC give plant operators 40 years of generating life before they must either close the plant or apply for a twenty-year license extension. Ninety percent of currently operating nuclear plants have already received or applied for license extensions.[7] The NRC is currently drafting guidelines for subsequent license renewal applications, which would extend the overall operating age to 80 years for a plant. These guidelines are scheduled to be published by the end of 2017 and may help postpone nuclear retirements in the US.[8] At some point, however, the aging US nuclear reactor fleet will have to be retired and replaced by something else. SMRs provide one potential option to replace aging energy infrastructure in the US.

As mentioned above, SMRs take advantage of mass production, rather than economies of scale. Because they are modular, SMRs can be mass produced and scaled up or down to meet demand. Modules can be added or taken away, allowing power plants to grow with towns and making them more adaptable to regional needs. The smaller size also allows for lower fabrication and shipping costs.

Because they are small, it is also easier to include safety measures to prevent accidents with SMRs. Large reactors often require electric pumps to move coolant through the reactor core and instances of power failure can shut down those pumps, causing the reactor to overheat and melt down. Smaller reactors have less piping and require less coolant, so they do not require pumps and back-up generators to keep coolant moving. Instead they rely on properties of physics to circulate coolant. This is known as a passive safety measure, meaning a loss of power to the plant will not require human intervention to prevent a meltdown because the reactor will naturally do so on its own.[9] SMRs also emit zero carbon during electricity production, which, in an age of ever-growing concern over climate change and support for renewable energy, makes nuclear a potentially attractive means of producing reliable, baseload power.[10]

Recently, the NRC has worked with three reactor designers on SMR design approvals: NuScale Power, BWXT mPower, and SMR Inventec.[11] Each of these SMR designs is a type of light water reactor (LWR), which is by far the most used and established type of nuclear reactor in use in the United States.[12] Because the regulatory framework has largely already been established for light water reactors, new reactors utilizing LWR technology face the path of least resistance when applying for design certification.

The NRC is also working with other reactor designers on non-LWR small reactor designs, such as Transatomic Power's Molten Salt Reactor and X-energy's Modular High Temperature Gas Cooled Reactor.[13] Due to the innovative nature of these technologies, the regulatory process is expected to take longer than their LWR counterparts. These technologies, however, could deliver benefits similar to the SMRs based on LWR technology.

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6 U.S. Energy Information Administration. (2017, May 12). *U.S. nuclear capacity and generation expected to decline as existing generators retire*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=31192; U.S. Energy Information Administration. (2017, January 5). *Annual Energy Outlook 2017*. p 6. Retrieved from https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

7 U.S. Energy Information Administration. (2017, May 12). *U.S. nuclear capacity and generation expected to decline as existing generators retire*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=31192

8 United States Nuclear Regulatory Commission. (2017, July 21). *Subsequent License Renewal.* Retrieved from https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html

9 Nayak, A.K., Sinha, R.K. (August 2007). *Role of passive systems in advanced reactors*. Progress in Nuclear Energy. Vol. 49. Issue 6. p 486-498. Retrieved from http://www.sciencedirect.com/science/article/pii/S0149197007000686

10 U.S. Energy Information Administration. (2017, January 10). *Nuclear Power and the Environment*. Retrieved from https://www.eia.gov/energyexplained/index.cfm/data/index.cfm?page=nuclear_environment

11 United States Nuclear Regulatory Commission. (2017, May 10). *Small Modular Reactors (LWR designs)*. Retrieved from https://www.nrc.gov/reactors/new-reactors/smr.html

12 *Ibid*.

13 United States Nuclear Regulatory Commission. (2017, July 26). *Advanced Reactors (non-LWR designs)*. Retrieved from https://www.nrc.gov/reactors/new-reactors/advanced.html#visStrat

Advantages of Nuclear as a Fuel Source

Nuclear power offers a number of advantages over traditional fossil fuel and renewable energy sources. Nuclear energy is an incredibly efficient fuel source, is one of the lowest carbon-emitting sources of energy production, and can produce reliable levels of electricity for years on end. These unique characteristics make nuclear a valuable source of energy production in a country's energy portfolio.

Specific energy is a measurement used to compare how much energy a fuel source can produce per unit of mass (i.e. kilowatt-hours per kilogram). In terms of specific energy, nuclear fuel is unmatched by any other fuel source. One kilogram of uranium-235, the fuel source used in nuclear reactors, has a specific energy almost 71,000 times larger than a kilogram of natural gas and almost 163,000 times larger than a kilogram of coal.[14] A good way to illustrate this point is to compare fuel consumption at a coal power plant versus a nuclear power plant of the same size. A 1,000 MWe nuclear power plant requires around 30 tons of uranium fuel per year to operate, while a coal-fired plant of the same size would require 3.4 million tons of coal to produce the same amount of electricity.[15]

In addition to fuel efficiency, nuclear power is the only reliable source of dispatchable power other than hydropower that does not produce air pollution during power generation.[16] All energy sources cause some level of pollution, whether it be during construction, fabrication, mining for fuel, or electricity production. On average, nuclear power plants produce similar amounts of greenhouse gas emission as wind turbines, and much less than solar, oil, natural gas, and coal power production.[17] However, once electricity production begins, nuclear plants produce zero greenhouse gas emissions.[18]

Nuclear plants offer significant benefits over wind and solar farms because nuclear reactors can produce large amounts of reliable power. This reliability is necessary to meet consistent minimum demand from municipalities, and to avoid brownouts or blackouts. Coal and natural gas are typically used to meet demand because renewable technologies like wind and solar are weather-dependent and thus intermittent. Their energy output can drop drastically if the wind stops blowing or the sun stops shining. Nuclear power plants can run continuously for years or decades, providing customers with a constant, reliable electricity source with the added benefit of zero air pollution.

Lower Upfront Costs than Large Reactors

Typical nuclear power plants are major engineering feats, requiring hundreds of thousands of metric tons of concrete and steel.[19] Understandably, these plants require massive upfront capital investments from firms and customers to finance construction costs. Modern estimates put the cost of a 1,000 megawatt nuclear plant at $10 billion.[20] Because of the size and complexity of these nuclear reactors, construction times may reach upwards of ten years, if not

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14 Hanania, J., Heffernan, B., Jenden, J., Leeson, R., Mah, T., Martin, J., Stenhouse, K., & Jason Donev. (n.d.). *Energy Density*. Retrieved from http://energyeducation.ca/encyclopedia/Energy_density

15 World Nuclear Association. (March 2017). *The Nuclear Fuel Cycle*. Retrieved from http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/nuclear-fuel-cycle-overview.aspx ; Ervin, E.K. (n.d.). *Nuclear Energy: Statistics* [PDF document]. Retrieved from http://home.olemiss.edu/~cmchengs/Global%20Warming/Session%2017%20Nuclear%20Energy%20-%20Statistics/Nuclear%20Energy.pdf

16 U.S. Energy Information Administration. (2017, January 10). *Nuclear Power and the Environment*. Retrieved from https://www.eia.gov/energyexplained/index.cfm/data/index.cfm?page=nuclear_environment; U.S. Energy Information Administration. (2017, January 10). *Hydropower and the Environment*. Retrieved from https://www.eia.gov/energyexplained/index.cfm/data/index.cfm?page=hydropower_environment

17 World Nuclear Association. (2016). *Greenhouse gas emissions avoided through use of nuclear energy*. Retrieved from http://www.world-nuclear.org/nuclear-basics/greenhouse-gas-emissions-avoided.aspx

18 U.S. Energy Information Administration. (2017, January 10). *Nuclear Power and the Environment*. Retrieved from https://www.eia.gov/energyexplained/index.cfm/data/index.cfm?page=nuclear_environment

19 Peterson, P. F., Zhao, H., & Petroski, R. (2005, February 4). *Metal And Concrete Inputs For Several Nuclear Power Plants*. p 8. Retrieved from http://fhr.nuc.berkeley.edu/wp-content/uploads/2014/10/05-001-A_Material_input.pdf

20 Pierobon, J. (2017, January 26). At least in the Southeast, the future of nuclear is brightening. *Southeast Energy News*. Retrieved from http://southeastenergynews.com/2017/01/26/at-least-in-the-southeast-the-future-of-nuclear-is-brightening/

more. The Watts Bar 2 reactor in East Tennessee that came online in 2016 took 42 years to complete.[21] Such long timeframes force investors to wait long periods to turn a profit and create high levels of uncertainty. A lot can change during a decade or more, including regulation and energy prices from competing sources that may undermine the profitability of the nuclear reactor.

The Shoreham Reactor in New York, for example, was one such victim of regulation and changing political opinion. Construction on the plant began in 1973, but due to political opposition and increased costs caused by new regulatory mandates, the plant never came online. Opposition from county legislators ultimately led to the plants closing in 1983, leaving ratepayers with a bill for $6 billion and leaving the Long Island Lighting Company leaning on mounds of credit to avoid bankruptcy.[22]

Westinghouse Electric Co LLC declared Chapter 11 bankruptcy early in 2017 as a result of delays and cost overruns at the Vogtle and VC Summer reactors being built in the southeast. The Vogtle plant is a brand new, two-reactor site in Georgia and the VC Summer is a currently operable nuclear plant in South Carolina that planned to build two new reactors with Westinghouse technology.[23] The Vogtle plant was approved for construction by the NRC in 2012 — the first to be approved in 33 years. The plant was expected to begin producing power in 2017 at an expected cost of $14 billion. Southern Company, the utility customer buying the plant from Westinghouse, was awarded an $8.3 billion loan from the Department of Energy to help with construction costs.[24]

Owners of both the Vogtle and Summer projects hoped to take advantage of the Nuclear Production Tax Credit that was included in the 2005 Energy Policy Act. The act was passed in hopes of encouraging a re-emergence of nuclear power in the United States.[25] Nuclear plants hoping to qualify for the credit, however, must begin electricity production by 2020. Unfortunately, that does not look likely for either project. The bankruptcy of Westinghouse has created uncertainty about the $8.3 billion federal loan guarantee to Southern Co. to help build the Vogtle plant, and has put the entire project at risk.[26] South Carolina Electric and Gas Company abandoned construction of the new Summer reactors in August 2017 and utility customers in South Carolina are stuck paying for them.[27] Customers of South Carolina Electric and Gas now pay 18 percent of their monthly bills to cover costs of the abandoned reactors. State-owned utility Santee Cooper raised customers' rates 5 times for the same reason.[28]

The major upfront investments required to build large scale nuclear reactors have proven to be a problem for the nuclear industry.[29] Small modular reactors are expected to decrease the up-front capital investments required for nuclear systems by building smaller, more flexible power plants. The modularity of the plants means that much of the construction may occur in a controlled manufacturing facility so that they can be delivered to the site ready

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21 Adams, R. (2016, October 19). Watts Bar 2, First New US Nuclear Plant Since 1996, Is Now Commercial!. *Forbes*. Retrieved from https://www.forbes.com/sites/rodadams/2016/10/19/watts-bar-is-now-commercial/#163a855f3680

22 Wald, M. L. (1984, August 24). Loans by 14 banks to protect Lilco from bankruptcy. *The New York Times*. Retrieved from http://www.nytimes.com/1984/08/24/nyregion/loans-by-14-banks-to-protect-lilco-from-bankruptcy.html ; Hiserodt, E. (2008, July 6). A Tale of Two Reactors. *The New American*. Retrieved from https://www.thenewamerican.com/tech/energy/item/7056-a-tale-of-two-reactors

23 Hartman, D. (2017, April 24). *Westinghouse bankruptcy epitomizes failures of electricity monopolies*. Retrieved from http://www.rstreet.org/2017/04/24/westinghouse-bankruptcy-epitomizes-failures-of-electricity-monopolies/

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25 Nuclear Energy Institute. (April 2016). *The Facts About Federal Subsidies for Energy: Nuclear Energy Does Not Dominate Federal Spending*. Retrieved from https://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/Nuclear-Subsidies_Fact-Sheet.pdf?ext=.pdf

26 Maloney, P. (2017, April 3). *Westinghouse bankruptcy puts $8.3B in federal loan guarantees for Vogtle plant at risk*. Retrieved from http://www.utilitydive.com/news/westinghouse-bankruptcy-puts-83b-in-federal-loan-guarantees-for-vogtle-pl/439508/

27 PR Newswire. (2017, July 31). *South Carolina Electric & Gas Company To Cease Construction And Will File Plan Of Abandonment Of The New Nuclear Project*. Retrieved from https://seekingalpha.com/pr/16901340-south-carolina-electric-and-gas-company-cease-construction-will-file-plan-abandonment-new

28 Plumer, B. (2017, July 31). U.S. Nuclear Comeback Stalls as Two Reactors Are Abandoned. *The New York Times*. Retrieved from https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html?_r=0

29 Thomas, S. (2012). *Economics of nuclear energy.* Retrieved from http://gala.gre.ac.uk/7728/

for installation. However, supply chains and manufacturing experience in the nuclear industry have atrophied substantially over decades of inactivity in the US nuclear industry. Westinghouse attempted to build some parts of the AP-1000 reactor as modular systems and encountered a number of complications during the process.[30] SMR vendors will need to do a better job of establishing supply chains and manufacturing standards if they want to avoid cost overruns.

NuScale estimates their first-of-a-kind SMR plant at Idaho National Laboratory will take 3 years to construct at a cost of less than $3 billion.[31] Due to passive safety features, estimated costs to staff the facility are also much lower than traditional nuclear facilities. It is important to keep in mind, however, that these costs are estimates, and ultimately these plants are still at the mercy of political opinion, potential delays, and competing prices from other fuel sources.

Improved Safety Features of SMRs

Nuclear power is already the safest form of commercial electricity production in use anywhere in the world. Fewer deaths have been attributed to nuclear energy per unit of electricity production than hydropower, solar power, and even wind power.[32] Yet, despite its safety record, public and political perception of the dangers of nuclear energy remains a major impediment to the nuclear industry. Since the invention of nuclear reactors 60 years ago, 3 major accidents have had a major impact on the public perception of the safety of nuclear energy. These accidents have driven the development of the regulatory climate in the US.

The first major accident was a severe reactor-core meltdown at the Three Mile Island Plant in New York in 1979. A combination of a stuck release valve and malfunctioning sensors resulted in a loss of coolant, leading to the core overheating and eventually melting down. The containment vessel, however, contained almost all of the radioactive material. The amount of radioactive material released into the environment was equal to one-sixth the amount of radiation used during a chest x-ray.[33] No adverse effects from this meltdown have ever been observed, nor are they expected since the containment vessel performed as designed.[34]

The next major plant failure was the 1986 Chernobyl reactor meltdown in Ukraine. The failed reactor design was a design unique to Eastern Bloc countries and failed to incorporate a number of safety measures included in western reactor designs. A newly constructed reactor was undergoing tests when operators who failed to follow adequate safety measures lost control of the fission process, leading to a core meltdown, fires, and an explosion of the containment vessel that released radioactive material into the atmosphere and surrounding land. In all, around 30 deaths have been attributed to the meltdown. These were firemen and operators that received lethal doses of radiation or life ending injuries. The adverse health effects from radiation exposure are harder to measure in the populations surrounding Chernobyl. It is the only nuclear accident that resulted in deaths from radiation poisoning.[35]

The most recent nuclear failure occurred at the Fukushima-Daiichi Plant in Japan in 2011. A 9.0 magnitude earthquake which occurred just off the coast of Japan created 2 large tsunami waves that eventually crashed into the plant a few minutes apart. The tsunami flooded power supplies and damaged seawater pumps that were necessary

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30 Flitter, E., Hals, T. (May 2017). How two cutting edge U.S. nuclear projects bankrupted Westinghouse. *Reuters*. Retrieved from http://www.reuters.com/article/us-toshiba-accounting-westinghouse-nucle-idUSKBN17Y0CQ

31 NuScale Power. (2017). *Construction Cost for a NuScale Nuclear Power Plant*. Retrieved from http://www.nuscalepower.com/smr-benefits/economical/construction-cost ; NuScale Power. (2017). *A Cost Competitive Nuclear Option for Multiple Applications*. Retrieved from http://www.nuscalepower.com/smr-benefits/economical

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33 Ervin, E.K. (n.d.). *Nuclear Energy: Statistics* [PDF document]. Retrieved from http://home.olemiss.edu/~cmchengs/Global%20Warming/Session%2017%20Nuclear%20Energy%20-%20Statistics/Nuclear%20Energy.pdf

34 United States Nuclear Regulatory Commission. (2014, December 12). *Backgrounder on the Three Mile Island Accident*. Retrieved from https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

35 World Nuclear Association. (November 2016). *Chernobyl Accident 1986*. Retrieved from http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx

to keep the reactors cooled. As a result of the loss of power, 4 reactors underwent meltdowns. No deaths have been attributed to radiation exposure from the Fukushima failure, but the Japanese government did evacuate over 100,000 people from the area.[36]

Each of these incidents have led to increased regulation standards from the NRC, which increase the cost of certification for new reactor designs. Because SMRs are so much smaller than standard nuclear reactors, they require fewer mechanical parts and safety measures to prevent severe accidents, which means a lower probability for mechanical failure. Each of the three meltdowns listed above occurred as a result of mechanical failure and human error, which caused a loss of coolant in the reactor core and led to overheating and an eventual meltdown. This type of meltdown should be much less likely with an SMR.

SMRs are often described as walk away safe. This means once the fission reaction has begun, operators could technically walk away and leave them running with no fear of catastrophic meltdown. Nuscale and SMR Inventec's reactors both rely on gravity and convection, rather than pumps, to circulate coolant. This removes the need for pumps to circulate coolant, which would fail if the plant ever lost power, leading to reactor core meltdowns like those that occurred at Chernobyl and Fukushima.[37] Transatomic's reactor uses an electrically cooled salt "plug" that sits below the fuel. In an event of power loss, the salt heats up, becomes a liquid, and the fuel falls through it and into a containment system where it will gradually cool and condense back into a solid.[38]

The inherent safety of these reactors means many of the safety regulations passed to keep larger reactors operating safely are potentially unnecessary or excessive for SMRs. The current required safety zone for reactors, for example, is a 10-mile radius around the plant. The size and safety features of SMRs would not require nearly as large of a safety zone, and a reduction in required safety zoning could allow plants to be built closer to population centers.[39] This could also reduce the cost of transmitting electricity because SMRs could be located nearer to where electricity is demanded.

Flexibility of SMR Technology

The smaller, modular nature of SMRs provide additional benefits above and beyond cost reduction. Due to their size, SMRs provide smaller electricity markets with the option of including nuclear power in their production portfolio and enable larger markets the option to scale production as demand grows. A traditional 1,000 MWe nuclear power plant will produce enough electricity in a year to meet the power demands of a large city like Boston.[40] In contrast, smaller reactors like NuScale's 50 MWe reactor will produce enough electricity in a year to power a Boston suburb of around 55,000 homes or small city like Fairbanks, Alaska.[41]

The lower electricity production means smaller, remote communities in places like Alaska could begin to consider nuclear as a potential source of electricity generation. In 2010, the Alaska State Legislature enacted the Alaska Sustainable Energy Act, which repealed the state moratorium on nuclear electric power.[42] Following that repeal, the state legislature commissioned a report on the viability of SMRs in Alaska from the University of Alaska Fairbanks

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36 World Nuclear Association. (April 2017). *Fukushima Accident*. Retrieved from http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx

37 NuScale Power. (2017). *Safety Features of the Nuclear Design*. Retrieved from http://www.nuscalepower.com/smr-benefits/safe, SMR LLC. (2017). *Safe and Secure.* Retrieved from https://smrllc.com/features/safe-and-secure/

38 Transatomic Power. (2017). *The Science*. Retrieved from http://www.transatomicpower.com/the-science/

39 X-energy. (2017). *The Xe- 100 Series: A different kind of nuclear reactor*. Retrieved from https://www.x-energy.com/

40 Ervin, E.K. (n.d.). *Nuclear Energy: Statistics* [PDF document]. Retrieved from http://home.olemiss.edu/~cmchengs/Global%20Warming/Session%2017%20Nuclear%20Energy%20-%20Statistics/Nuclear%20Energy.pdf

41 United States Nuclear Regulatory Commission. (2012, February 24). *What is a Megawatt?*. Retrieved from https://www.nrc.gov/docs/ML1209/ML120960701.pdf ; Rettig, M. (2011, January 23). Why nuclear energy is on hold for Alaska. *Fairbanks Daily News-Miner*. Retrieved from http://www.newsminer.com/news/local_news/why-nuclear-energy-is-on-hold-for-alaska/article_51958987-2a69-5528-aa4b-fd2755913460.html

42 Nuclear Energy Institute. (January 2017). *State Legislation and Regulations Supporting Nuclear Energy*. p 1. Retrieved from https://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/statelegislationregulation.pdf?ext=.pdf

Center for Energy and Power. The report highlighted the need for energy sources in remote areas where it may be difficult and costly to deliver traditional fuel sources like coal and natural gas.[43] Fuel transportation costs could be greatly reduced or eliminated because nuclear plants do not require a continuous fuel supply. Some SMRs are being designed to run for a decade or more without needing to be refueled, which would also greatly reduce the amount of spent fuel created by the reactor. Many also operate on a closed fuel cycle, meaning once fuel has been consumed, it is reprocessed and reused by the reactor.[44] This offers a distinct advantage for SMR power generation over coal or natural gas in remote areas.

For larger municipalities and utilities, SMRs also provide advantages to larger nuclear plants. NuScale's Power Module, for example, has been designed to contain up to 12 reactors, each of which can be operated from a central control room.[45] This means cities can scale their power output as population and electricity demand grow. It also means the refueling cycle can be staggered so that only one reactor at a time needs to shut down to be refueled, allowing the rest of the plant to continue running.[46] Typical large-scale nuclear reactors must completely shut down to exchange used nuclear fuel for a new batch. A typical schedule for existing reactors is to exchange one-third of their fuel every 18-24 months.[47]

SMRs also have the capability of providing heat for industrial, commercial, and residential applications. Traditional nuclear systems have been used as cogeneration plants, providing heat for suburbs and industrial applications in places like Sweden and the UK.[48] SMRs could fill this role for remote areas with smaller populations. However, because some of the proposed designs operate at higher reactor temperatures, SMRs could also provide heat for industrial applications that a large nuclear plant cannot provide.[49] This capability opens up additional markets for SMRs beyond electric power production.

If SMRs capture a significant share of the power market, the construction of SMR components should experience process improvements similar to any other standardized production system. The experience gained by producing more units leads to improvements. Having multiple SMR providers also adds a competitive nature to the market, causing each SMR provider to seek out improvements at every stage of the design, construction, and operation processes. The scalable nature of SMRs offers more potential for the use of nuclear energy and a greater range of possibilities for innovation, improvements, and implementation in the energy sector.

Regulatory Barriers

Despite the numerous benefits of SMRs, there are still issues that will need to be resolved for the technology to compete on the energy market. SMRs are nuclear reactors and as such still require large up-front investments, lengthy design and construction timelines, and standards for decommissioning and disposal of radioactive spent fuel. Some of these issues can be resolved through innovation, but many of them are products of excessive government regulation. Nuclear power's ability to be competitive in the energy market will require solving or mitigating these issues.

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45 NuScale Power. (2017). *How NuScale Technology Works*. Retrieved from http://www.nuscalepower.com/our-technology/technology-overview

46 NuScale Power. (July 2013). *NuScale Power Modular and Scalable Reactor*. Retrieved from https://aris.iaea.org/PDF/NuScale.pdf

47 Barq, V. (2012, May 8). *What Happens During a Refueling Outage?*. Retrieved from http://neinuclearnotes.blogspot.com/2012/05/what-happens-during-refueling-outage.html

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49 Nuclear Energy Institute. (n.d.). *Small Reactor Designs.* Retrieved from https://www.nei.org/Issues-Policy/New-Nuclear-Energy-Facilities/Small-Reactor-Designs

Growth of Regulation in the US

Licensing a nuclear reactor in the United States is a long, expensive, and arduous process. The entire process can stretch on for a decade or more and will cost the reactor designers millions—if not billions of dollars. These costs are borne out of years of growth in regulatory bloat in the nuclear industry and are a major impediment to building new reactors today. The early years of nuclear power were highlighted by major government support and optimism, which was key to the expansion of the industry in the 50's and 60's.[50] In the 1970's, however, public and political favor towards nuclear power shifted. The establishment of the Nuclear Regulatory Commission, combined with an increase in environmental regulation and the partial meltdown at Three Mile Island, marked the end of support for nuclear energy by the majority of the population.[51]

The passage of the National Environmental Policy Act in 1969 and the subsequent ruling that nuclear power facilities had to comply with the act gave anti-nuclear groups footing to oppose plant approvals. From 1970 to 1972, 73 percent of all applications for nuclear licenses were challenged in court.[52] The Atomic Regulatory Commission—which had overseen the nuclear energy sector since 1946—was dismantled in 1974.[53] Legislators were concerned that there was a conflict of interest in allowing the same commission to both regulate and promote the industry. In its place, they established the Nuclear Regulatory Commission (NRC) to oversee the regulation and licensing of reactors.[54]

Even after the creation of the NRC, litigation against the nuclear industry continued to rise. During the NRC's first year of oversight, 15 judicial cases were brought against the agency and 20 new regulations were proposed. Less than 10 years later, in 1983, 21 judicial cases brought against the NRC resulted in 535 proposed regulations. Over that 8-year time span, the NRC faced a total of 430 lawsuits and proposed 2,349 new regulations in response.[55]

In 1979, Four years into the NRC's oversight of the the nuclear industry, the Three Mile Island (TMI) accident occurred, effectively altering the way the NRC handled regulation. After TMI, the NRC became much more aggressive about the regulations they imposed and the way they were enforced. Some of these changes included mandatory retrofits, increased training requirements, and more extensive reporting requirements.[56] The new standards imposed by the NRC post-TMI increased the cost of building a nuclear plant so much that over 100 planned or partially-constructed plants were abandoned.[57]

Evaluations of the impact of regulation on nuclear power profitability and progress as an industry illuminate just how much these regulations changed the industry. A 1995 report from the EIA found that between the years of 1975 and 1987, NRC regulations were the single biggest factor contributing to increases in plant operation and maintenance costs.[58] According to a study published that same year in the Journal of Applied Econometrics, "[nuclear power

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50 Clarke, L. (June 2985). *The Origins of Nuclear Power: A Case of Institutional Conflict*. Social Problems. Vol. 32, No. 5. p 474-487. Retrieved from http://www.jstor.org/stable/800776

51 U.S. Office of Technology Assessment. (February 1984). *Nuclear Power in an Age of Uncertainty*. Ch. 8. Retrived from http://large.stanford.edu/courses/2015/ph241/llanos1/docs/8421.pdf

52 Spencer, J. (2007, November 15). *Competitive Nuclear Energy Investment: Avoiding Past Policy Mistakes*. Retrieved from http://www.heritage.org/environment/report/competitive-nuclear-energy-investment-avoiding-past-policy-mistakes

53 Energy Reorganization Act of 1974. 42 USC §§ 5801-5879. Retrieved from https://www.nrc.gov/docs/ML0224/ML022410201.pdf

54 Energy Reorganization Act of 1974. 42 USC §§ 5801-5879. Retrieved from https://www.nrc.gov/docs/ML0224/ML022410201.pdf

55 Delmas, M., & Heiman, B. (2001). Government Credible Commitment to the French and American Nuclear Power Industries. *Journal of Policy Analysis and Management*, 20(3), p 447.

56 Rust, J., & Rothwell, G. (July 1995). Optimal response to a shift in regulatory regime: the case of the US nuclear power industry. *Journal of Applied Economics*, 10, p S81. Retrieved from http://www.jstor.org/stable/2285015?seq=1#page_scan_tab_contents

57 Parenti, C. (2011, March 22). After Three Mile Island: The Rise and Fall of Nuclear Safety Culture. *The Nation*. Retrieved from https://www.thenation.com/article/after-three-mile-island-rise-and-fall-nuclear-safety-culture/

58 Energy Information Administration. (1995, April 21). *An Analysis of Nuclear Power Plant Operating Costs: A 1995 Update*. Retrieved from https://digital.library.unt.edu/ark:/67531/metadc711072/m2/1/high_res_d/67785.pdf

plants] are also substantially less profitable: over 90% of the expected discounted profits from continued operation of existing NPPs have been eliminated in the post-TMI period."[59]

A 2016 journal article from researchers at Carnegie Mellon University and the Breakthrough Institute performed an in-depth examination of the effect post-TMI regulations had on nuclear plant construction. The authors found that the overnight cost of construction of nuclear power plants (OCC)—a baseline used to examine building costs in the nuclear industry—increased exponentially after 1970. By 1978, the OCC for plants had increased by 50-200% over 1970 cost levels.[60] The amount of building materials required to meet regulatory standards increased over the same period, with mandates requiring 41 percent more steel, 27 percent more concrete, 50 percent more piping, and 36 percent more electrical wiring.[61]

The Carnegie Mellon report also found that plants which were under construction when the Three Mile Island accident occurred in 1979 took 2 to 3 times as long to build as those completed before the accident, and the median overnight costs of construction nearly tripled.[62] These increased construction times and added delays resulted in more cost increases for nuclear plants.

It is important to note a number of economic factors also created challenges for the nuclear industry in the 1970's, including declining growth in electricity demand and increasing interest rates, which peaked at 20 percent in 1980.[63] The effects of these economic issues, exacerbated by increased regulatory costs, played a major role in the decline of the nuclear industry in the United States. Some attempts have been made to streamline regulatory processes since TMI, but the changes that have been made have done little to help reduce the cost of compliance. Recently, regulatory setbacks have plagued the now-bankrupt Westinghouse and the construction of its AP-1000 reactors. The NRC established the Aircraft Impact Assessment in 2009 in response to the September 11, 2001 terrorist attacks. The new assessment stipulated that the containment building, which houses the nuclear reactor, must be strong enough to withstand direct impact from an airplane. Westinghouse was required to comply with the new assessment despite being 7 years into its design submissions process (it submitted an application for the AP-1000 reactor design in 2002). After redesigning the containment building, the NRC then scrutinized the ability of the new design to withstand tornadoes and earthquakes. Westinghouse did not receive final design approval until 2011.[64]

According to Lake Barrett, a former official at the U.S. Nuclear Regulatory Commission, "The cost overrun situation is driven by a near-perfect storm of societal risk-aversion to nuclear causing ultra-restrictive regulatory requirements, construction complexity, and lack of nuclear construction experience by the industry."[65] The NRC's ability to mandate design changes and retrofits even after giving approval for a design, along with their habit of inundating the nuclear industry with regulatory standards, has increased costs and construction times for nuclear plants and made it more difficult for them to compete with other forms of electricity generation.

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59 Rust, J., & Rothwell, G. (July 1995). Optimal response to a shift in regulatory regime: the case of the US nuclear power industry. *Journal of Applied Economics*, 10. Retrieved from http://www.jstor.org/stable/2285015?seq=1#page_scan_tab_contents

60 Lovering, R. J., Yip, A., & Nordhaus, T. (April 2016). Historical construction costs of global nuclear power reactors. *Energy Policy, 91*, p 371-382. https://doi.org/10.1016/j.enpol.2016.01.011

61 Cohen, B. L. (1990). Costs of Nuclear Power plants- What Went Wrong? *The Nuclear Energy Option* (ch 9). Retrieved from http://www.phyast.pitt.edu/~blc/book/chapter9.html

62 Lovering, R. J., Yip, A., & Nordhaus, T. (April 20162016, April). Historical construction costs of global nuclear power reactors. *Energy Policy, 91*, p 371-382. https://doi.org/10.1016/j.enpol.2016.01.011

63 Hultman, N., Koomey, J. (May 2013). *Three Mile Island; The driver of US nuclear power's decline?* .
Bulletin of the Atomic Scientists. Vol. 69, Issue 3. p 63-70. Retrieved from http://www.tandfonline.com/doi/abs/10.1177/0096340213485949?scroll=top&needAccess=true&journalCode=rbul20

64 Flitter, E., Hals, T. (May 2017). How two cutting edge U.S. nuclear projects bankrupted Westinghouse. *Reuters*. Retrieved from http://www.reuters.com/article/us-toshiba-accounting-westinghouse-nucle-idUSKBN17Y0CQ

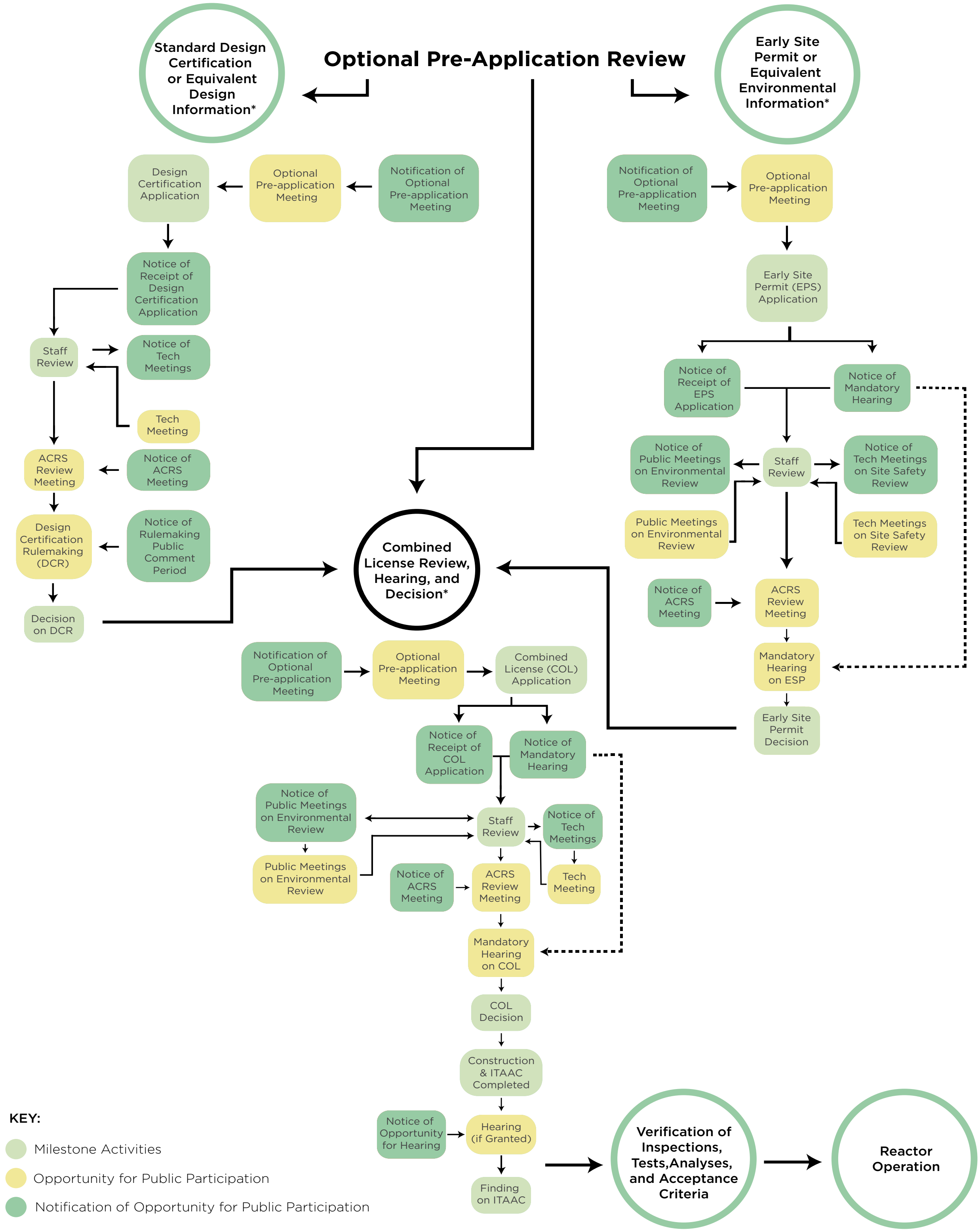
65 Stapczynski, S. (2017, February 2). *Next-Generation Nuclear Reactors Stalled by Costly Delays*. Retrieved from https://www.bloomberg.com/news/articles/2017-02-02/costly-delays-upset-reactor-renaissance-keeping-nuclear-at-bay

The Licensing Process

The process to license a reactor for commercial electricity production in the US requires reactor designers to apply for three different licenses: a design certification, an operating license, and a site permit. Each of these licensing processes are lengthy and complex, full of applications that require years to prepare, submit, and review. Figure 1 outlines the licensing process from beginning to end. This process was developed by regulators with an in-depth knowledge of traditional LWR technology, and is not well adapted to some newer forms of reactor technology like SMRs.[66]

66 Lester, R. K. (2016). A Roadmap for U.S. Nuclear Energy Innovation. *Issues in Science and Technology*. p 48. Retrieved from: http://web.mit.edu/nse/lester/files/RKL_Roadmap_for_US_Nuclear_Energy_Innovation.pdf

Figure 1: The Federal Nuclear Licensing Process[67]



67 United States Nuclear Regulatory Commission. (July 2004). *Nuclear Power Plant Licensing Process*. Retrieved from https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0298/br0298r2.pdf

The NRC oversees this entire process and makes all final decisions on application submissions. Reactor designers are required to pay the full expense of consultation with the NRC.[68] For example, when NuScale consulted with the NRC to clarify regulations and learn more about the design certification process, NuScale was required to pay for the time and effort the NRC staff used to provide this information. In addition, now that the NRC is reviewing NuScale's design certification application, NuScale will be required to pay for the NRC staff's time and effort to evaluate the applications. This requirement is unique to the nuclear industry. No other regulatory body is funded purely by the industry it regulates. Those costs, along with a timeframe that typically stretches on for a decade or longer, present a major barrier for SMR technology.

The NRC has made various attempts to create a more efficient regulatory environment for new reactor technology, including the addition of a set of rules known as 10 CFR part 52 in 1989 that was intended to standardize design certification, introduce early site permits, and create a combined license for construction and operation.[69] Despite these changes, a number of issues still persist in the licensing process.

Design Certification

The NRC established the standardized design certification process as part of 10 CFR part 52 in an effort to improve the safety of nuclear reactors and decrease the number of issues occurring during the licensing process.[70] This new standardized process, however, places an enormous burden on reactor designers. Under current design certification standards, reactor designers must fill out an application for certification to submit for review. These applications take years to complete and are, on average, more than 10,000 pages long.[71] Once the application is submitted, NRC engineers must review it. The review process is expected to take between 27 and 48 months, barring any unexpected delays.[72] Once a reactor design is certified, the design is valid for 15 years with an option to renew the certification for another 10 to 15 at the end of that period. The NRC has certified 6 reactor designs since 1989 and has 5 currently under review, one of which is suspended.[73]

NuScale Power submitted the first ever Design Certification Application (DCA) for a SMR in December 2016, and their experience offers some insight into the amount of resources necessary to compile an application. The finalized 12,000 page document was prepared over 8 years and took 2 million staff hours to complete.[74] The final cost of completing the application came to $500 million.[75] The NRC estimates that the application will take 40 months to review, during which time NuScale will be required to pay around $270 per man-hour charged by the NRC to process the application. Those costs will come in addition to the 40,000 hours already leveraged by NuScale for

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68 United States Nuclear Regulatory Commission. (2017, August 29). *Schedule of Fees*. Retrieved from https://www.nrc.gov/reading-rm/doc-collections/cfr/part170/part170-0021.html

69 Early Site Permits; Stand Design Certifications; and Combined Licenses for Nuclear Power Reactors. (1989, April 18). *Federal Register 54(73)*. 10 CFR pt 2, 50, 51, 52, 170. p 15372. Retrieved from https://cdn.loc.gov/service/ll/fedreg/fr054/fr054073/fr054073.pdf

70 United States Regulatory Commission. (December 2009). *Frequently Asked Questions About License Applications for New Nuclear Power Reactors*. p 2. Retrieved from https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0468/br0468.pdf

71 Adams, R. (2011, December 7). *Examples of regulatory costs for nuclear energy development*. Retrieved from https://atomicinsights.com/examples-of-regulatory-costs-for-nuclear-energy-development/

72 Duke Energy. (2012, January 17). *NRC New Nuclear Licensing Process*. Retrieved from https://nuclear.duke-energy.com/2012/01/17/nrc-new-nuclear-licensing-process

73 United States Nuclear Regulatory Commission. (2017, May 19). *Design Certification Applications for New Reactors*. Retrieved from https://www.nrc.gov/reactors/new-reactors/design-cert.html

74 NuScale Power. (2017). *NuScale Status in the Regulatory Process*. Retrieved from http://www.nuscalepower.com/our-technology/nrc-interaction; NuScale Power. (2016, December 31). *NuScale Power, LLC Submittal of the NuScale Standard Plant Design Certification Application (NRC Project No. 0769)*. Retrieved from https://www.nrc.gov/docs/ML1701/ML17013A229.pdf

75 Hall, B. (2017, January 12). NuScale files NRC application. *Gazette Times*. Retrieved from http://www.gazettetimes.com/news/local/nuscale-files-nrc-application/article_d983facb-24e9-58eb-9c7d-04e009fa2fba.html

consultation with the NRC while preparing the application.[76] The entire design certification process is expected to cost over $1 billion by the time it is finished.[77]

The design certification process is a massive technical and financial undertaking, as shown by the time and money NuScale invested in their application. The length and technical nature of each application places an equally large burden on the NRC during the review process. In 2011, as the NRC was finishing its certification of the AP1000, Chairman Gregory Jaczko admitted that they would have to slow down their review of licenses due to staffing limitations.[78] For vendors who have spent hundreds of millions of dollars compiling a DCA, these delays mean months or years of additional waiting before they can begin turning a profit.

GE Hitachi is one example of the NRC's inability to adequately process applications, and the setbacks that can occur. GE Hitachi submitted a Design Certification Application for its Economic Simplified Boiling Water Reactor (ESBWR) in 2005, 3 years after Westinghouse submitted their DCA for the AP1000 reactor. The NRC prioritized resource use to focus on the AP1000 application, implying they did not have the ability to work on both simultaneously.[79] This caused the certification process for GE Hitachi to drag on for 9 years before they finally received a final approval for their reactor design.[80]

The design certification process places an enormous burden on reactor designers and acts as a major barrier to entry into the nuclear market for new designs. NuScale has relied on the DOE to fund a significant portion of its certification process.[81] BWXT chose to postpone the certification process for its mPower SMR in 2017 due to lack of funding and major losses already accumulated during the process.[82] Reform is needed to make the certification more feasible for innovators. Current costs and timeframes, coupled with the uncertainty of receiving certification, incentivize the use of old technology rather than promote innovation.

Construction and Operation

The 1989 NRC regulatory reforms introduced a new provision for licensing the construction and operation of nuclear reactors. Under the new regulations vendors can apply for a Combined Operating License (COL). Prior to 1989 vendors had to apply for the license to build the plant, followed by an application to operate the plant after construction was completely finished.[83] Each step of the pre-1989 application process required hearings and reviews on environmental, health, and safety assessments. The second round of hearings related to the operating license — performed after construction was finished — left plant owners exposed to litigation from plant opponents and

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76 Adams, R. (2017, March 16). *NRC accepted NuScale's DCA. Will it complete its review on time? Estimated completion July 2020*. Retrieved from https://atomicinsights.com/nrc-accepted-nuscales-dca-review-complete-july-2020/ ; Conca, J. (2017, January 15). NuScale First To Submit SMR Nuclear Application to NRC. *Forbes*. Retrieved from https://www.forbes.com/sites/jamesconca/2017/01/15/nuscale-first-to-submit-smr-nuclear-application-to-nrc/#3bac7709581e

77 Banse, T. (2016, April 14). *Nuclear Developer Details Timeline For Trailblazing Reactor Debut In Idaho*. Retrieved from http://kuow.org/post/nuclear-developer-details-timeline-trailblazing-reactor-debut-idaho

78 Trigaux, R. (2011, December 7). Federal regulator of nuclear power plants says it may slow license renewal for aging nukes. *Tampa Bay Times*. Retrieved from http://www.tampabay.com/blogs/venturebiz/content/federal-regulator-nuclear-power-plants-says-it-may-slow-license-renewal-aging-nukes

79 Brumm, J. (2011, October 13). NRC delays reactor certification to study Japan damage. *Reuters*. Retrieved from http://www.reuters.com/article/usa-nuclear-nrc-idUSN1E79C1NF20111013

80 United States Nuclear Regulatory Commission. (2017, April 12). *Issued Design Certification- Economic Simplified Boiling-Water Reactor (ESBWR)*. Retrieved from https://www.nrc.gov/reactors/new-reactors/design-cert/esbwr.html

81 Nuclear Energy Institute (NEI). (2014, May 28). *NuScale, DOE Sign $217M Contract to Fund SMR Project*. Retrieved from https://www.nei.org/News-Media/News/News-Archives/NuScale,-DOE-Sign-217M-Contract-to-Fund-SMR-Projec

82 Davis, W. (2017, March 16). mPower Consortium Halts Project. *American Nuclear Society*. Retrieved from http://ansnuclearcafe.org/2017/03/16/mpower-consortium-halts-project/

83 Blanton, M. S., Graham, W. A., Jr., & Ronnlund, M. W. (2010). The NRC's Improved Licensing Process for Commercial Nuclear Power Plants. *infrastructure, 49(4)*, p 7. Retrieved from http://www.balch.com/-/media/files/insights/publications/2010/08/the-nrcs-improved-licensing-process-for-commercial/files/infrasu10/fileattachment/infrasu10.pdf

often led to extensive cost overruns as design changes and retrofits were required before operation could begin.[84] The Shoreham Plant, mentioned earlier in the report, was one victim of this process. Required changes to the facility imposed as a result of the operation license review led to delays and increased costs that ultimately prevented the plant from producing any electricity.

The introduction of COLs was meant to address the problem of a separate operation license review process by combining the construction and operation licensing application processes. This combination was meant to ensure that all issues could be resolved before construction began.[85] The NRC, however, has run into a new set of problems with the COL process. On paper, the process seemed like a major improvement. The introduction of the standardized licensing process would lead to a pool of already-approved reactor designs that utilities and power companies could choose from. Once an approved design was chosen, a COL application could be submitted. The NRC takes 32 months to review COLs which reference a certified reactor design, and 48 to 60 months for any which reference a design still undergoing certification.[86] Average plant construction is estimated to take around 48 months, plus another 6 to get the plant fueled up and running.[87]

This process was supposed to proceed sequentially, as shown in the first part of Figure 2. However, that would require applicants to wait at least 4 years for a design certification, another 3-4 years for a COL, and another 4-5 years to build the plant before operation. Applicants may instead choose to pursue the COL in parallel in the hopes of shortening the process, as shown in the second part of Figure 3. NRC Chairman Jaczko admitted in 2009 that increased activity from applicants pursuing COLs in parallel was placing too much of a strain on NRC staff and leading to mistakes. Some of this increase in applications was driven by the 2005 Energy Policy Act, which incentivized utilities to submit applications for reactors preemptively in order to meet the 2008 deadline to receive benefits.[88]

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84 Ibid.

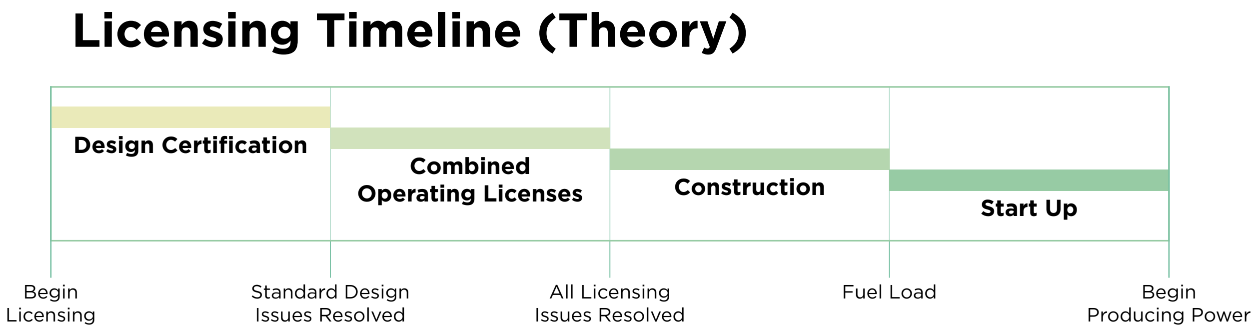
85 Jaczko, G. B. (2009, February 12). *New Opportunities to Invest in Nuclear Safety*. Retrieved from https://www.nrc.gov/docs/ML0904/ML090430301.pdf

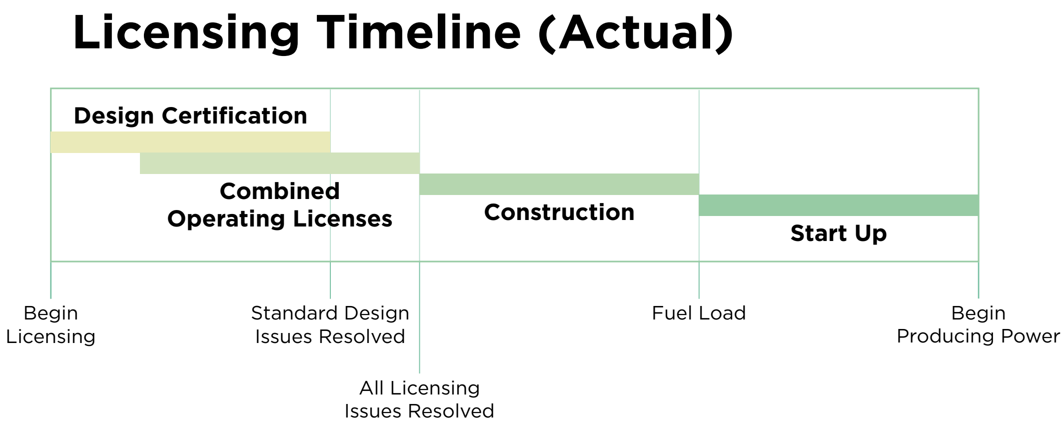
86 United States Regulatory Commission. (December 2009). *Frequently Asked Questions About License Applications for New Nuclear Power Reactors*. p 10. Retrieved from https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0468/br0468.pdf

87 Blanton, M. S., Graham, W. A., Jr., & Ronnlund, M. W. (2010). The NRC's Improved Licensing Process for Commercial Nuclear Power Plants. *infrastructure, 49(4)*, p 11. Retrieved from http://www.balch.com/-/media/files/insights/publications/2010/08/the-nrcs-improved-licensing-process-for-commercial/files/infrasu10/fileattachment/infrasu10.pdf

88 Jaczko, G. B. (2009, February 12). *New Opportunities to Invest in Nuclear Safety*. Retrieved from https://www.nrc.gov/docs/ML0904/ML090430301.pdf

Figure 2[89]





SMRs may potentially run into similar issues with parallel COL submissions. With zero certified SMR designs, any customers hoping to use the new technology will either have to wait years for designs to be approved before submitting a COL or submit a COL while SMR technology is under review. Under the current rules, the incentives for submitting an early COL certainly outweigh those of waiting. The DOE actually awarded NuScale $16.7 million to help its first customer, Utah Area Municipal Power Supply (UAMPS), complete a COL. NuScale expects it will be completed in 2018, 3 years before their SMR design will be certified.[90] The inefficiencies of the Combined Operating License process, like the Design Certification Application, add unnecessary costs and uncertainty to the licensing of innovative reactor technologies like SMRs.

Waste Disposal

A significant roadblock to the development of any nuclear energy in the United States is the issue of waste disposal. While nuclear reactors do not produce carbon emissions, they do create nuclear waste that emits high levels of radiation. The United States does not currently have a long-term solution for the storage and disposal of commercial

89 Blanton, M. S., Graham, W. A., Jr., & Ronnlund, M. W. (2010). The NRC's Improved Licensing Process for Commercial Nuclear Power Plants. *infrastructure, 49(4)*, p 7. Retrieved from http://www.balch.com/-/media/files/insights/publications/2010/08/the-nrcs-improved-licensing-process-for-commercial/files/infrasu10/fileattachment/infrasu10.pdf

90 NuScale Power. (2017). *NuScale Wins U.S. DOE Funding For Its SMR Technology*. Retrieved from http://www.nuscalepower.com/about-us/doe-partnership

nuclear waste. A 2003 study released by MIT highlighted the lack of a permanent waste disposal solution, claiming it as one of the largest obstacles to the development of additional nuclear energy in the United States.[91]

SMRs, however, can take advantage of new nuclear reactor technologies that can help address the waste disposal issue. Many new reactor designs use nuclear fuel more efficiently, reducing the amount of waste created. Others, such as high-temperature gas-cooled reactors or fast neutron reactors, are able to recycle spent nuclear fuel, allowing for a further increase in efficiency and a decrease in the amount of produced nuclear waste.[92] Additionally, standardized SMR designs could allow for a systematic approach to waste disposal, which could simplify waste disposal if a permanent disposal facility was built.

While SMRs and new technologies may be able to help resolve the nuclear waste problem from a technical standpoint, the issue is in large part a result of political forces. In 1982, Congress passed the Nuclear Waste Policy Act, which assigned several agencies within the federal government the task of creating and regulating a permanent waste disposal repository deep underground, later chosen to be Yucca Mountain in Nevada. The act also included a deadline of 1998 for the facility to open, and established the Nuclear Waste Fund as a means to help pay for the repository.[93]

Legal challenges and political conflict delayed any major progress on the facility until, in 2009, Secretary of Energy Steven Chu announced that the DOE would not be moving forward with the project.[94] One such political challenge to Yucca Mountain occurred in 2008 when the EPA extended the requirement for radiation containment levels from 10,000 years to 1 million years.[95] This created a significant roadblock to the completion of the project, as planning for 1 million years of compliance is a much more difficult undertaking.

The Nuclear Waste Fund, however, had been collecting money from ratepayers, as well as accruing interest, since the 1980's. Today it contains roughly $40 billion.[96] Nuclear plant operators payed a tenth of a cent per kilowatt-hour produced to the fund, which was collected until 2014. In return, the DOE took responsibility for the safe disposal of nuclear waste.[97] These costs were passed on to ratepayers in the form of higher electricity prices, but the DOE has failed to repay consumers by completing its responsibility.

In 2012, the Blue Ribbon Commission on America's Nuclear Future, appointed by President Obama, released its recommendations for solving the issue of nuclear waste disposal in the US. One of its recommendations was to ensure that the money raised via the Nuclear Waste Fund was accessible to agencies to use for the fund's intended purpose of financing a national nuclear waste repository.[98]

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91 Massachusetts Institute of Technology. (2003). *The Future of Nuclear Power*. Retrieved from http://web.mit.edu/nuclearpower/pdf/nuclearpower-summary.pdf

92 Kessides, I. N. (2012). The future of the nuclear industry reconsidered: Risks, uncertainties, and continued promise. *Energy Policy*, 48, p 185-208. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0301421512004053#bbib60

93 United States Department of Energy. (2004, March). *Nuclear Waste Policy Act*. Retrieved from:https://energy.gov/sites/prod/files/edg/media/nwpa_2004.pdf

94 Gorman, T. (2002, April 9). Nevada Governor Vetoes Nuclear Waste Dump Site. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2002/apr/09/news/mn-36917 ; Bullis, K. (2009, May 14). Q&A: Steven Chu. *MIT Technology Review*. Retrieved from https://www.technologyreview.com/s/413475/q-a-steven-chu/

95 Reuters. (2009, February 17). NRC *adopts 1 million year rule for Yucca Mountain*. Retrieved from https://www.reuters.com/article/us-energy-nuclear-yucca/nrc-adopts-1-million-year-rule-for-yucca-mountain-idUSTRE51G6XN20090217

96 U.S. Subcommittee on Environment and the Economy of the Committee on Energy and Commerce. (2015, December 3). *The Nuclear Waste Fund: Budgetary, Funding, and Scoring Issues*. Serial No. 114-106. Retrieved from https://www.gpo.gov/fdsys/pkg/CHRG-114hhrg99813/pdf/CHRG-114hhrg99813.pdf

97 Northey, Hannah. (2014, May 16). *Nuclear Waste: U.S. ends fee collections with $31B on hand and no disposal option in sight*. Retrieved from: https://www.eenews.net/stories/1059999730

98 Department of Energy. (January 2012) *Blue Ribbon Commission on America's Nuclear Future*. Retrieved from: https://energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf

Also included in the commission's report was a comparison of reactor technologies and fuel cycles. Fast reactors utilizing "closed" fuel cycles, where nuclear waste is recycled into fuel, would reduce the amount uranium needed for fuel by 95 percent. Most countries that use nuclear energy, on the other hand, utilize "open" fuel cycles that do not recycle fuel. By altering this strategy and reprocessing spent fuel, SMRs with advanced reactor technology could also reduce the amount of near-surface wastes by 95 percent.[99] The lack of a national waste repository has forced nuclear plant owners to store the waste on-site, and storage of high-level waste is now over capacity.[100] Strict regulation of the use of existing nuclear waste could also stifle this technology and its potential waste-recycling benefits.

Despite the many complications surrounding nuclear waste disposal, SMRs implementing reprocessing technologies could help address the issue. Additionally, the creation of a national nuclear waste solution, as outlined in the Nuclear Waste Policy Act, would eliminate one potential barrier to the development of all kinds of new nuclear resources.

Policy Recommendations

Small modular nuclear reactors present a promising option for the United State's future energy portfolio, but regulations in the US are threatening to kill off the technology before it can even reach the market. While the regulation of nuclear technology is important to ensure the safety of the American people, nuclear energy should also be considered a viable option for producing reliable, pollution-free power. A number of options can and should be explored to ease the regulatory burden on SMR technology. These options range from revising the current licensing process to altering the methods and incentives the Nuclear Regulatory Commission has for collecting revenues. Our recommendations are outlined below:

1. Review the existing design certification process and make necessary changes to accommodate the fundamental differences SMRs have from existing large-scale reactors due to scale and operational philosophy.

The NRC license approval process is geared toward large-scale light water reactors. Because of this history, the NRC is not prepared to regulate a technology that is dramatically different from the existing nuclear fleet and is based on standard manufacturing techniques.

In July 2013, DOE and NRC established a joint initiative to address portions of the licensing framework. The first phase of this work was completed in December 2014 with the production of a guidance document. The NRC is in the process of implementing parts of this framework.

The design certification process should be accelerated by both the DOE and NRC working toward a framework that will accommodate the unique features of SMRs and lessen the uncertainty associated with the present licensing processes. SMRs are very different from traditional nuclear technology in size, technology, construction philosophy, and application. The regulatory environment needs to be adapted to account for these differences.

2. Congress should hold hearings to bring the NRC to account for long license evaluation and response time.

Despite a series of reforms, the NRC is not meeting its own timetables for license approval.

While the joint initiative between DOE and NRC is a step in the right direction, Congress has a role to play in the streamlining of the regulatory process. There are several instances where the company making an application is required to provide information "in a timely fashion." There is no corresponding accountability for timeliness on the NRC. Congress should use its legislative authority in oversight and appropriations to insure the NRC is performing reviews in an acceptable timeframe.

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99 Department of Energy. (January 2012) *Blue Ribbon Commission on America's Nuclear Future*. Retrieved from: https://energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf

100 Zhang, S. (2015, July 17). The plan for storing US nuclear waste just hit a roadblock. *Wired*. Retrieved from https://www.wired.com/2015/07/plan-storing-us-nuclear-waste-just-hit-roadblock/

The appropriate committees in both the House of Representatives and Senate should hold hearings on the lack of efficiency of the NRC in recent applications to determine if there are funding, personnel, or other issues leading to the poor performance of the NRC.

3. The requirement that applicants pay for consultation and the application process of the NRC should be removed by Congress.

Companies that request information and submit license applications to the NRC must pay for these processes with no guarantee of timely response. The NRC is the only regulatory body with this requirement.

The nuclear industry is the only industry that must pay the regulatory body for doing routine work. Because the SMR regulations are incomplete and under constant development, companies need guidance from the NRC to make prudent decisions on the development of new technologies. At present, companies have to pay the NRC for this information. In addition, when a company makes a design or license application, the company must pay the NRC to perform the evaluation.

Congress should eliminate this requirement and consider different funding mechanisms for the NRC.

4. Expand and formalize Department of Energy authority to host test reactors for data gathering and design testing

The physical infrastructure to build and test developmental nuclear reactors is expensive and subject to multiple levels of regulation.

The federal government owns many facilities that could be used by SMR developers to safely host test reactors. For example, the Idaho National Laboratory has a long history of civilian and naval reactor development. A process should be implemented where the NRC can give preliminary approval for test reactors under controlled circumstances that allow designers to develop the necessary data and safety procedures to apply for a full design certification. Then, DOE can serve as host for these facilities.

Congress should authorize the DOE to enter into agreements with SMR developers to host and provide technical assistance regarding facility safety and security.

5. Develop an effective long-term waste disposal solution to reduce developer uncertainty.

The Yucca Mountain facility has not been funded since 2010 and the civilian radioactive storage facilities at nuclear reactor sites are reaching critical storage levels.

Congress is re-opening the debate on Yucca Mountain. While a re-examination of the usefulness of the proposed waste facility is welcome, additional topics should be considered. Absent a significant change in policy, there is no near term resolution to the civilian nuclear waste problem. Instead of a "one size fits all" solution like Yucca Mountain, Congress should authorize private companies to store civilian waste material. Private sector innovation of waste disposal/recycling services could help address the existing on-site storage issues in the nuclear power industry.

Congress should authorize the NRC to develop regulations allowing processing and disposal of civilian nuclear waste outside the context of Yucca Mountain.

6. The Nuclear Regulatory Commission should initiate and develop a series of guidelines related to the SMR-specific possibility of interacting with industrial customers to provide power and thermal energy.

SMRs have the capability of providing industrial grade heat to nearby facilities, but the NRC has not published any guidelines on the safety requirements for having a nuclear reactor in close proximity to another industrial facility.

One characteristic of some of the SMR designs is that they can potentially provide heat energy for commercial/industrial application if the SMR is located near the partner process. There are many industrial process that need heat energy (in the form of steam) that could be provided by a SMR system. While the economic benefits could be substantial, locating near another facility conflicts with current NRC policy.

The NRC should develop standards for potential industrial uses of SMRs to open the possibility of industrial utilization of SMR technology and to reduce the uncertainty associated with these potential new uses.

7. Congress should revisit and possibly redesign the NRC's authority to impose regulations and standards after approval of design and construction plans.

The NRC has the authority to impose regulations on the design, construction, and operation of nuclear facilities even after the granting of the appropriate license. The license holders have no ability to challenge these retroactive regulations.

The ability to impose new requirements on a facility after granting a license is unique to the NRC. This dramatically raises the cost and uncertainty when constructing a new facility. Instead of allowing the NRC to retroactively impose regulations with no consideration for imposed cost and delays, a mechanism should be put in place by Congress where the NRC would have to develop a justification for the imposition of new regulations on facilities that have already received construction/operating permits. This justification would become part of the public record and would be subject to Congressional oversight.

Congress should revisit the NRCs authority to retroactively impose regulations on facilities after granting a license.