OREGON PSR PHYSICIANS FOR SOCIAL RESPONSIBILITY

Eyes Wide Shut:

Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors

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Executive Summary

NuScale Power, a small modular nuclear reactor development firm based in Portland, Oregon, is seeking approval from the U.S. Nuclear Regulatory Commission for the design of their initial reactor model. The company has an agreement with the Utah Association of Municipal Power Systems (UAMPS), a collection of small publicly-owned municipal utilities in Utah, California, Idaho, Nevada, New Mexico, and Wyoming, to deploy a first-of-its-kind plant of a dozen 60-megawatt (MW) pressurized water reactors grouped in a common containment facility at the Idaho National Laboratory site, assisted by a proposed power purchase agreement to sell some of the output to the US Department of Energy. As of August 2020, UAMPS has not found subscribers for all the power that this plant would produce if constructed.

The proposal is being pursued at a time when the American nuclear power industry has stalled, and two nuclear power plant projects initiated in Georgia and South Carolina have ended up costing many billions of dollars more than promised. The latter project has been abandoned, after $9 billion had been spent on the project, when Westinghouse entered into bankruptcy protection, and left ratepayers with a huge debt obligation much of which will likely be included in their power bills. The former project has doubled in cost and in its construction timeline, and is still not complete. These add to the long-standing and consistent questions about the cost competitiveness of new build nuclear power. NuScale's nearly 20 year-long history of changing reactor design offers reasons to be similarly concerned about its costs and timeline.

NuScale, and its parent company, Fluor Corporation, rely upon enormous subsidies from US taxpayers—the U.S. Department of Energy has invested hundreds of millions of dollars in development costs. Despite what NuScale might claim, there is no guarantee that the reactor system will receive all necessary regulatory approvals. The Nuclear Regulatory Commission and its Advisory Committee on Reactor Safeguards have flagged unresolved issues with the NuScale design that will have to be resolved at a future stage of licensing. NuScale's decision to further increase the electricity output per reactor unit in its design will require regulatory approval and could lead to further delays in licensing.

Even with this output increase the NuScale reactor design will not be competitive due to lack of economies of scale for production. In the nuclear industry, there is a long track record of understated cost estimates, especially in first-of-its-kind projects. These higher costs would not be sufficiently offset by claimed savings from factory production of modular reactors or lower cost public financing.

The estimated costs of the NuScale reactor design have been consistently going up. Just in the last five years, the estimated construction cost has gone up from around $3 billion in 2015 to $6.1 billion in 2020. Because the NuScale design might have to be modified to resolve the problems flagged by the Nuclear Regulatory Commission, there could be further cost increases even before construction starts. There is a long history of dramatic cost increases when paper designs are first constructed.

Another problem with the UAMPS proposal is uncertainty about the future of Fluor Corporation. Between October 2018 and August 2020, the company has lost 80 percent of its value on the New York Stock Exchange. These losses are, in large part, the result of bidding too low on fixed price contracts and not accurately revealing their financial status to stockholders, triggering an SEC investigation this year.

For all these reasons, UAMPS members may wish to consider ending their pursuit of small modular nuclear reactors and avoid the sunk costs of a project that is very unlikely to achieve its target price or produce electricity at a cost competitive with proven alternatives. Pursuing cheaper, currently available solar, wind, energy storage (batteries), and energy efficiency would be a more reliable path for UAMPS to shift to a carbon-free energy future.

As the American energy grid is increasingly fueled by renewable energy, there will most likely not be demand for full output from NuScale's proposed pilot small modular nuclear reactor plant. Any unsold output will of course, increase the unit costs of the rest. Load following capability claimed by NuScale for its reactor system design would be, if utilized, a financial negative, rather than an argument in favor of construction.

As has been true with other recent nuclear power projects in the US and in Europe, UAMPS members could be on the hook for extreme cost overruns and project cancellation, making it a risky proposition for them to continue investing in an untested, first-of-its-kind nuclear power facility

Introduction

The proposed NuScale reactor design is being considered for possible construction at the expense of Utah Associated Municipal Power Systems (UAMPS), "a political subdivision of the State of Utah that provides comprehensive wholesale electric-energy, transmission, and other energy services, on a nonprofit basis, to community-owned power systems… [in] Utah, California, Idaho, Nevada, New Mexico and Wyoming".[1] The proposed NuScale design is to be a pressurized water reactor (PWR) that is currently supposed to produce 60 megawatts (MW) of electrical power, although it is more correct to describe it as a 720 MW nuclear power plant since it is intended to be built only in a cluster of 12 units.

Although NuScale is now the leading small modular reactor (SMR) design in the United States, having submitted the first design certification application in this class to the U.S. Nuclear Regulatory Commission, there are several reasons to be concerned about constructing a power plant based on this design. These include lengthy delays in development and possibly licensing, the uncertain financial outlook of the main corporate investor in the reactor development, the high cost of electricity that the NuScale reactor system would generate, the constantly improving economics of renewable energy and storage technologies, the risk of accidents, the absence of a demonstrated solution for disposal of the radioactive waste that the reactor would produce in large quantities, and the likely decline in electricity demand in the near to medium term future. Further, if SMRs like NuScale are used as a backup to intermittent renewables like wind and solar energy, then it would further increase the cost of generating electricity at these nuclear plants. Given all these problems, proceeding with NuScale's proposal amounts to closing one's eyes to the impending waste of limited financial resources that would better serve ratepayers and the environment by investing in renewables, storage, and energy efficiency.

Background on Small Modular Reactors

SMRs, as the name suggests, produce relatively small amounts of power compared to the current nuclear reactor fleet; the average gross power rating of the reactors operating in the United States as of 19 April 2020 is 1076 MW. A small reactor is defined as one that generates less than 300 MW of electricity. The term modular is used to refer, in part, to the methods used in their manufacture and, in part, to the idea that one nuclear reactor with a large power output is replaced with many reactors with smaller power outputs.[2] SMRs have been advanced as a potential way to rescue the U.S. and European nuclear power industries, with moribund construction for some decades now. Globally, nuclear power has been declining from its historic maximum of 17.5 percent of electricity generated in 1996, down to about ten percent currently.[3] In the United States, the number of operating nuclear power plants has come down to 95 from a high of 112 in 1990.[4] During what was supposed to be the "nuclear renaissance", the United States Nuclear Regulatory Commission (NRC) received license applications for 31 new reactors.[5] Over the past ten years, 29 of these were cancelled due to the lack of economic viability. There are no prospects for any new construction of large nuclear plants in the United States in the foreseeable future, after the Vogtle and V. C. Summer projects in Georgia and South Carolina proved much more expensive than projected.[6] It is in the context of the lack of economic competitiveness of these larger reactor projects that SMRs are now being advocated.

There are dozens of SMR designs at different stages of development. The International Atomic Energy Agency lists 55 reactor designs in the 2018 edition of its booklet on SMRs; past editions came out in 2012, 2014, and 2016.[7] Roughly about half of these are Pressurized Water Reactors (PWRs), the predominant type of currently deployed nuclear reactor technology. These were originally developed in the 1950s and used to power nuclear submarines. The first commercial power reactor in the United States, at Shippingport in Pennsylvania, was a PWR and was designed to generate 60 MW of electricity. It is therefore not surprising that PWRs are the leading SMR designs as well.

The SMR idea is not new: small reactors date back to the first flush of nuclear reactor design and construction. In the 1950s, the U.S. Atomic Energy Commission funded the construction of several small power reactors that were declared to be "suitable both for use in rural areas and for foreign export".[8] But all these reactors ended up shutting down early because they were not economically competitive.[9] When one of these reactors, the Elk River Reactor in Minnesota, was shut down in 1968 following the appearance of cracks in the cooling system piping, the Rural Cooperative Power Association that owned it decided that it was not worth repairing because, as a spokesperson of the Association told the *Chicago Tribune*, "the reactor has not been too economical because it is too small”.[10]

The economics of proposed SMRs, including the NuScale design, are going to be just as adverse. Electricity from these proposed SMRs will not be competitive for exactly the same reason as the earlier small reactors: their power output is not adequate to make them profitable. We discuss the cost of generating power from the NuScale SMR design in greater length below. However, we note here that even today it is widely acknowledged that smaller nuclear plants “tend to be unprofitable more often than do large ones”.[11] This has led to several such smaller units being shut down for economic reasons in recent years.[12] At a combined total of 720 MW for a 12 reactor unit power plant, NuScale will definitely be a smaller sized facility and thus be economically challenged.

Despite this history, the U.S. Department of Energy (DOE) has continued to support SMRs since the 1980s. In 1988, the DOE claimed that there was “new interest in small and medium size reactors and in more advanced reactor concepts other than those marketed today.”[13] There was, in reality, only verbal interest and no such reactors were constructed. In 2001, again, the DOE’s Office of Nuclear Energy published a report that provided an overview of nine SMR designs and concluded that “the most technically mature small modular reactor (SMR) designs and concepts have the potential to be economical and could be made available for deployment before the end of the decade, provided that certain technical and licensing issues are addressed”.[14] None of the SMR designs that were evaluated were available for deployment by 2010, the end of that decade.

The latest round of SMR promotion started in 2012 when the DOE established a cost-share funding opportunity to cover expenses associated with research and development, design certification, and licensing, and selected two SMR designs for funding, the mPower design from Babcock & Wilcox and NuScale. The first of these was mPower. After the DOE had provided it $111 million in funding,[15] and mPower spent more than double that amount, the corporate entities in charge of mPower decided to essentially terminate the SMR project because they determined there was no market for it.[16]

Unlike the companies involved in mPower, which had multiple other products to sell, NuScale has only one product. So it persisted with developing its reactor design and accessed the $226 million in matching money offered by the DOE. In 2018, DOE provided another grant of US$40 million to NuScale.[17] As of 2019, NuScale had reportedly invested approximately US$850 million into SMR development, with the bulk of it coming from its parent company, the Fluor Corp. (described later), and a little more than a third coming from the federal government.[18] In March 2020, the Chairman and Chief Executive Officer of NuScale Power told the House Committee on Energy and Commerce that “Fluor and its investors contributed $643 million, or 67% of expenditures to date, and the Federal government has contributed $314 million” to make up a total of $957 million.[19]

There is more money coming from the government. In February 2020, the DOE reportedly “agreed to spend up to $350 million in new matching funds”.[20] According to this agreement, in the “initial project baseline” DOE would spend $263 million over the next five years and NuScale would have to match these funds. That would mean a total investment of $525 million. However, the agreement also envisions the possibility of the project cost escalating “to a ceiling of $700 million, with overruns to be split on a 50-50 basis”.[21] In all, then, just the initial investment on the development of the NuScale design amounts to around $1.5 billion.

Long in Development

The proposed NuScale reactor design began as the outcome of the Multi-Application Small Light Water Reactor project that was funded by the Nuclear Energy Research Initiative of the U.S. Department of Energy and carried out by Idaho National Laboratory, Oregon State University, and a consulting company called Nexant. According to the final report submitted in 2003, the project was intended to “develop the conceptual design for a safe and economic plant and to test the design feasibility”.[22] It resulted in a design for a plant with a net electrical output of35 megawatts.

The design had a discharge burnup of around 30 megawatt-days per kilogram (MWd/kg). The burnup represents the amount of thermal energy that the reactor can produce per unit of uranium; the greater the burnup, the lower the amount of fuel required and the lower the amount of radioactive waste produced by the reactor.

The project proponents also tried to evaluate its economics by considering construction in clusters of 30 such reactors to produce a total net electrical output of 1050 megawatts, i.e., roughly in the same ballpark as large reactors. For this configuration, the designers estimated the capital cost to be around $1.2 billion (overnight) or $1.3 billion inclusive of interest during construction, which translates to "$1,241 per kWe of capacity installed" for "the nth-of-a-kind (NOAK) plant in which the learning curve benefits have been fully achieved".[23] This cost estimate is in 2002 dollars and it translates to just over $1.8 billion or $1,700 per kWe in 2019 dollars. The learning is assumed to "happen when about four baseline plants have been built". The results of the economic modelling also called for the use of fuel with uranium enriched to 8 percent of the uranium-235 isotope, roughly twice the enrichment level used in most commercial nuclear plants in the United States.

NuScale Power, LLC was incorporated in 2007 and the Multi-Application Small Light Water Reactor acquired the name NuScale. The following year, in early 2008, NuScale Power started discussions with "the U.S. Nuclear Regulatory Commission, with the intention of submitting an application for design certification for the modular, scalable reactor technology".[24] By that time, the design output of the reactor had increased, to 40 MW in 2009, but so had the estimated costs. Paul Lorenzini, then CEO of NuScale, announced as part of fundraising that the "40 MW modules are expected to cost about $4,000 per kW… translating to $160 million apiece".[25]

The design power output subsequently went up to 45 MW while the design uranium enrichment level for the fuel came down to 4.95 percent or less of uranium-235.[26] By the time NuScale submitted its design certification application on December 31, 2016, the power output was increased again and the design was described as capable of producing "50 megawatts of electricity. A NuScale power plant can house up to 12 of these modules for a total facility output of 600 megawatts (gross)".[27] Finally, a year and a half after the application had been submitted to the Nuclear Regulatory Commission, NuScale announced that it had modified the design again and that it was now capable of producing 60 MW of electricity.[28] NuScale also claimed that the design change will result in "very minimal change in capital costs".

All of these power rating increases suggest that the NuScale reactor design, which is proprietary, and so not completely transparent, is not stable and has been continuously changing. They are also a clear indication that NuScale is not confident of its earlier assumptions regarding the economic benefits of smaller reactor sizes.

The date for when a NuScale reactor would be producing electricity has also been repeatedly pushed back. Soon after NuScale was incorporated as a company, its leading officials announced that in January 2008, "NuScale Power advised the US Nuclear Regulatory Commission of its intent to initiate preapplication reviews with a view towards submitting an application for design certification in 2010. The first preapplication meeting was held on 24 July 2008…With timely application for a combined construction and operating license (COL), a NuScale plant could be producing electricity by 2015-16".[29] For its part, the NRC bought into these projections and in October 2008, an NRC official projected that NuScale would submit an application for design certification in early 2010 and that review would be completed by early 2015.[30]

Within two years, those numbers had shifted and in 2010, SNL Energy's *Power Daily* reported that NuScale intended "to submit a design certification application to the NRC early in 2012" and was hoping "to have its first reactor online in 2018".[31] The same date was also reported by the OECD's Nuclear Energy Agency in its report on Small Modular Reactors from 2011. According to that report, NuScale was to have filed a licensing application in 2011 and had a targeted deployment date of 2018 for its first plant.[32] In 2010, the NRC even issued a notice in the Federal Registry that said "NuScale Power, Inc. (NuScale) has submitted a letter of intent to the U.S. Nuclear Regulatory Commission (NRC) for a design certification application in 2012".[33]

Those dates kept being pushed back and NuScale submitted its design for review only on the last day of 2016. In March 2017, the NRC accepted NuScale's application for full review and has commenced the design certification process that, according to officials, was "expected to take 40 months".[34] The following year, in April 2018, NRC completed its first phase of the review but the next stages are expected to take longer. NuScale officials themselves admit that the NuScale design "faced significant challenges meeting Nuclear Regulatory Commission (NRC) regulations".[35]

The schedule for completion of the plant's construction has slipped too. In 2018, NuScale announced "plans to commence site preparation in 2021, with nuclear construction commencing in 2023" as well as "plans for the first NuScale Power Module™ to achieve commercial operation in 2026 and the remaining 11 modules in 2027". [36] In July 2019, UAMPS announced that construction would begin "in 2023, with the first 60 MW module becoming operational in 2026. Other modules would come on-line soon thereafter".[37] The latest "development status and overview" document for the UAMPS Carbon Free Power Project (CFPP) from

NUSCALE DELAYS

2008

NuScale announces it plans to submit its application in 2010 and be producing electricity by 2015-16.

2010

NuScale announces it would submit its application in early 2012, planning to have its first reactor online by 2018.

2019

UAMPS announces initial electricity generation to begin 2026

2020

UAMPS announces initial electricity generation to begin 2029

Figure 1: NuScale's Shifting Timeline

July 2020 states that "initial generation" of the first module is "slated for 2029", with completion of the remaining eleven modules a year later, in June 2030.[38] That is a decade and a half after what was initially promised—and those dates of 2029-2030 presume that there are no further significant delays.

But there are many reasons to expect delays. In March 2020, the NRC's Advisory Committee on Reactor Safeguards issued a letter warning that the "design and performance of the steam generators have not yet been sufficiently validated".[39] The steam generator is what converts the heat produced by the nuclear reactions into steam that drives a turbine that ultimately generates electricity. The problem that the Advisory Committee was referring to had to do with the design of this structure being unique; no other commercial nuclear power plant uses a steam generator of a similar design. This, the Advisory Committee pointed out, "introduces different failure modes" resulting in their "design and performance" not being sufficiently validated. There are two concerns with the steam generator, one having to do with instability and the other to do with corrosion, due to "accelerated wear of the alloy 690TT steam generator tubing material".[40]

One of the members of the Committee was so concerned by this idea that they published an additional comment attached to the letter. These stated the member's belief that "the steam generator integrity should be addressed before issuance of the design certification by either resolving the issue, or by providing a risk-informed argument why it does not present a safety concern".

The NRC has concurred with the ACRS findings.[41] The NRC's staff have said that further analysis or testing results to "demonstrate the design and performance of the steam generators" will have to be included as part of the application for the license to construct and operate the reactor.[42] The decision not to require resolution before the design certification is issued indicates that NuScale and the NRC expect that it will take a lot of time to address the problem with the steam generator. Thus, whoever is going to apply for the license to construct and operate the reactor will have to deal with the concerns highlighted by ACRS and NRC, in addition to raising the finances and selling the power.

There is a separate problem that arose recently because NuScale is carrying out another round of design changes. This, in turn, is because NuScale realized that "under certain conditions, the emergency core cooling system (ECCS) actuated later than expected and resulted in higher containment water level accumulation than previously determined".[43] This has pushed back the timeline for NRC's completion of the next phase of the safety review of the design by nearly six weeks.[44]

Finally, in June 2020, another ACRS letter to the NRC highlighted concern about boron dilution. Boron is used to control the reactivity of the reactor. If the boron concentration is reduced, it could increase the reactivity, thereby lowering safety. The ACRS letter expressed concern about "a potential reactivity insertion accident and core damage".[45] This was grave enough a concern that the ACRS stated that it "cannot reach a final conclusion on the safety of the NuScale design until the issue of a potential reactivity insertion accident due to boron dilution in the downcomer is resolved".[46]

Thus, NuScale's timelines are already being pushed back during the licensing process itself and various safety concerns have been identified. More delays are therefore to be expected.

Another important source of future delay is NuScale's decision to increase the power rating per module from 50 MW to 60 MW because what NuScale has submitted for review is the older design with a power rating of 50 MW. As a NRC spokesperson told *Nuclear Intelligence Weekly* in July 2019, "NuScale must apply separately for the uprate" and that the current schedule only applies to the 50 MW design.[47]

An even more recent design change is a shift to air cooling (discussed later). According to an UAMPS spokesperson, this design change has resulted in the schedule for completion being pushed back.[48] This change in the reactor design, as well as others made by NuScale after it submitted its design for review in 2016, will have to be evaluated by NRC. In the event that the NRC identifies any safety problems as a result of these design changes, that would necessitate further changes to the NuScale reactor design.

Design changes have been a frequent source of delay in licensing estimates throughout the history of nuclear power. In the case of the AP1000 reactors constructed in Sanmen, China, because of design changes carried out after construction had started, "Westinghouse had to rip out equipment that had already been installed and start again or undertake lengthy re-examinations of engineering work".[49] Likewise, in the case of the AP1000 reactors constructed in Georgia and South Carolina, a major source of delay and cost overruns was blamed on Westinghouse because "'several thousand' technical and design changes [were] made after work had already started on various components".[50] Those cost overruns eventually led the VC Summer project to be abandoned after billions were spent.

Potential Investment Problems

As described earlier, the development of the NuScale design has cost nearly a billion dollars but even under the company's optimistic projections, the investment needed to get NRC approval for the 60 MW design is an additional half a billion to $700 million.[51] At least half of these new investments will have to come from the private sector unless current funding agreements are modified to further burden taxpayers.

NuScale's majority shareholder is the Fluor Corporation, which is reported to have spent $27 million in 2011 to acquire the company.[52] In recent years, Fluor Corporation has seen its financial foundations in trouble. Fluor Corporation's stock prices have declined from roughly $60 a share in October 2018 to as low as $3.40 in March 2020.[53] It subsequently recovered somewhat and was a little over $11 as of early August but the outlook is still bleak, in part because it is being investigated by the Securities and Exchange Commission.[54] The company also disclosed that the Justice Department has subpoenaed documents concerning a fixed-price federal project.[55] Depending on the risk allocation ultimately reflected in the relevant agreements, the proposed UAMPS project may resemble a fixed price contract of the sort that Fluor has said that it will no longer undertake.

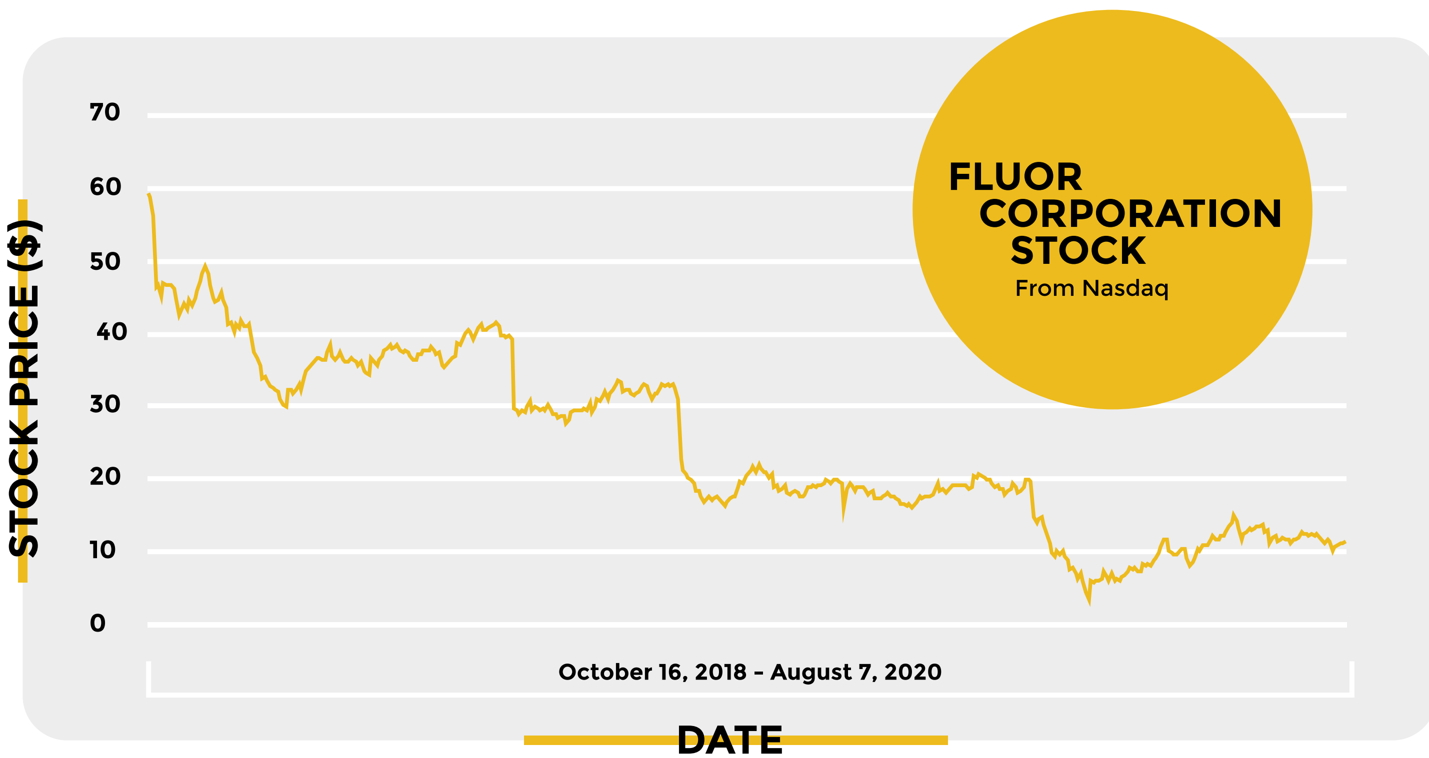

Figure 2: Prices of Fluor Corporation Common Stock from Nasdaq.com

This stock decline is not attributable to the economic downturn caused by the coronavirus pandemic. In February 2020, prior to U.S. stay home orders, the company lost 48 percent of its value. The market watching website *The Motley Fool* argued that the slump "was driven by a notable amount of bad news from the engineering and design company. It revealed write downs and impairments of over $1 billion as part of its preliminary earnings results issued on Feb. 18. Fluor also noted that the company is under investigation by the Securities and Exchange Commission, which is contributing to a delay in the filing of its annual 10-K report".[56] Fluor Corporation's efforts to rescue itself by building a new management team do not seem to have convinced market watchers and the advisory company Seeking Alpha has warned that "turnaround is difficult".[57]

These problems have led financial analysts to advise Fluor to abandon NuScale. In May 2019, a senior Credit Suisse analyst wrote to investors that there was "opportunity for positive change at Fluor" but went on to suggesting that the firm could reduce "underperforming investments," including its NuScale small modular nuclear reactor startup "which is long overdue, in our opinion".[58] While Fluor has not followed that advice, it has cut its own investment into NuScale down to the bone. In February 2020, when discussing its earnings for 2019 (Year-End), Fluor Corporation announced that it was "excluding NuScale expenses" from its guidance because it was expecting that "additional funding will be provided by third-party investors".[59] Whether there will be other outside investors in the project and how much they will invest is an open question. But as we have seen earlier, the NuScale design still requires a few hundreds of millions of dollars in investment, even if all goes according to plan and there are no further problems with the licensing process.

Estimated Cost of Construction and Risk of Cost Overruns

The projected cost of constructing the NuScale design has also gone up. As mentioned earlier, the cost estimate of the Multi-Application Small Light Water Reactor in 2003 was $1,241/kW in 2002 dollars, or $1,718/kW when inflated to 2019 dollars. In 2015, NuScale "unveiled a detailed breakdown of projected costs" at the Platts nuclear energy conference in Washington.[60] According to this estimate, the total price for the (then) 600 MW unit would be $2.895 billion or $5,078 per kilowatt.[61] These figures are in 2014 dollars and translate to $3.1 billion for the plant or $5,499 per kilowatt in 2019 dollars. The cost estimate assumes that the construction is essentially completed in 51 months ("mobilization to mechanical completion") and does not include what are called owners costs, which includes the construction and operating license application fees, that NuScale estimated at $300 million.

According to the 2018 announcement by NuScale, the estimated cost per unit of generation capacity came down "from an expected $5,000 to approximately $4,200" when it moved to a design that could produce 60 MW of electricity with "very minimal change in capital costs".[62] Thus, one might presume that NuScale's estimate of construction costs for its 720 MW unit would still be $3.1 billion (in 2019 dollars). However, one would be wrong. For, in a February 2018 presentation, UAMPS stated that the "Estimated Development Costs to the Completion of Development" was $587 million and "Cost of Acquisition and Construction of the Initial Facilities (Preliminary Estimated Costs)" was $4,238 million.[63] In other words, the cost increased.

Since then both of these figures have gone up further according to the Amended Budget & Plan of Finance for the CFPP project from July 14, 2020.[64] The first figure is now estimated at $1,375 million, up from $587 million, and the total cost has increased to $6,124 million. In other words, the cost estimate of $3.1 billion (in 2019 dollars) from 2014 has nearly doubled in six years.

This can be expected to go up even further if and when construction starts. This is exemplified by the high construction costs of the AP1000 nuclear reactors being constructed in South Carolina and Georgia over the last decade, as well the many other units canceled at earlier stages of planning. The AP1000 reactor design was developed by Westinghouse, once the leading nuclear power plant vendor around the globe. During the initial phase, as it first unveiled the AP1000 design, Westinghouse offered a number of cost estimates. In 2001, for example, "based on quotes and estimates from vendors and standard labor rates for Kenosha, Wisconsin", Westinghouse told the U.S. Department of Energy that the AP1000 would cost $1,365/kW for the first unit (assuming "that the first unit is ordered as part of a pair of units and the costs include procurement costs, construction costs, post-construction costs, contingency, owner's costs, and the first time engineering") and that this would come down to $1,040/kW for the "Nth-of-a-kind plant".[65] These figures are in 2000 dollars, and translate to $1,966/kW for a first-of-a-kind plant and $1,498/kW for a Nth-of-a-kind plant in 2019 dollars.

These cost figures were endorsed by the Nuclear Energy Institute, whose senior vice president's testimony before the Senate Energy Committee on February 3, 2005, asserted that this estimate of "less than $1,400 per kilowatt" (namely the $1,365/kW from five years back) "has a solid analytical basis, has been peer-reviewed, and reflects a rigorous design, engineering and constructability assessment".[66]

By the time the first AP1000 construction projects were being proposed and costed, the estimates had jumped to $3,787/kW for the V.C. Summer 2&3 units and $4,745/kW for the Vogtle Units.[67] Both of these figures are in 2007 dollars and translate to $4,603/kW and $5,767/kW respectively in 2019 dollars. In other words, even the cost estimate before start of construction was around 2.5 times the estimate initially offered by Westinghouse.

The V.C. Summer project was cancelled after spending over $9 billion and customers with the South Carolina Electric & Gas company are on the line to pay a substantial portion of this debt as part of their monthly power bills over the next 20 years even though the two nuclear reactors were unfinished and never generated any electricity.[68] The updated estimate for the one remaining AP1000 project, according to a 2018 Massachusetts Institute of Technology report, is $8,600/kW (or $8,700/kW in 2019 dollars).[69] This continues to go up as the Vogtle project continues to report cost increases; in June 2020, the Georgia Public Service Commission staff and outside experts projected a further escalation of around $1 billion to the total cost and an "astounding 80%" component test failure rate.[70] Thus, the construction cost has gone up by at least a factor of 4.5, and this is even before the project has been completed.

There has been a similar increase with the construction period too. When they were proposed, Westinghouse projected that the AP1000 would take three years for construction (from the first concrete pour to commercial operation).[71] No AP1000 project has been completed anywhere near that construction period.[72]

The AP1000 is by no means a one-off case. There is a long history of cost overruns and wrong estimates with nuclear power plants around the world.[73] Indeed one study of construction cost overruns showed that 175 out of the 180 nuclear projects examined had final costs that exceeded the initial budget, on average by 117 percent; they took on average 64% more time than projected.[74] The maximum cost and time overruns in that dataset were $16.6 billion and 149 months, respectively. There are multiple potential reasons for these cost overruns, including technical reasons (such as inadequate data, and lack of experience), economic reasons (vendors underestimating costs because it is in their economic interest), psychological explanations (cognitive bias towards optimism), and political causes (strategic misrepresentation when forecasting and during advocacy).[75] This history and the applicability of the many underlying drivers identified in the literature to the proposed UAMPS project suggest that there is a high likelihood that NuScale is underestimating the final cost.

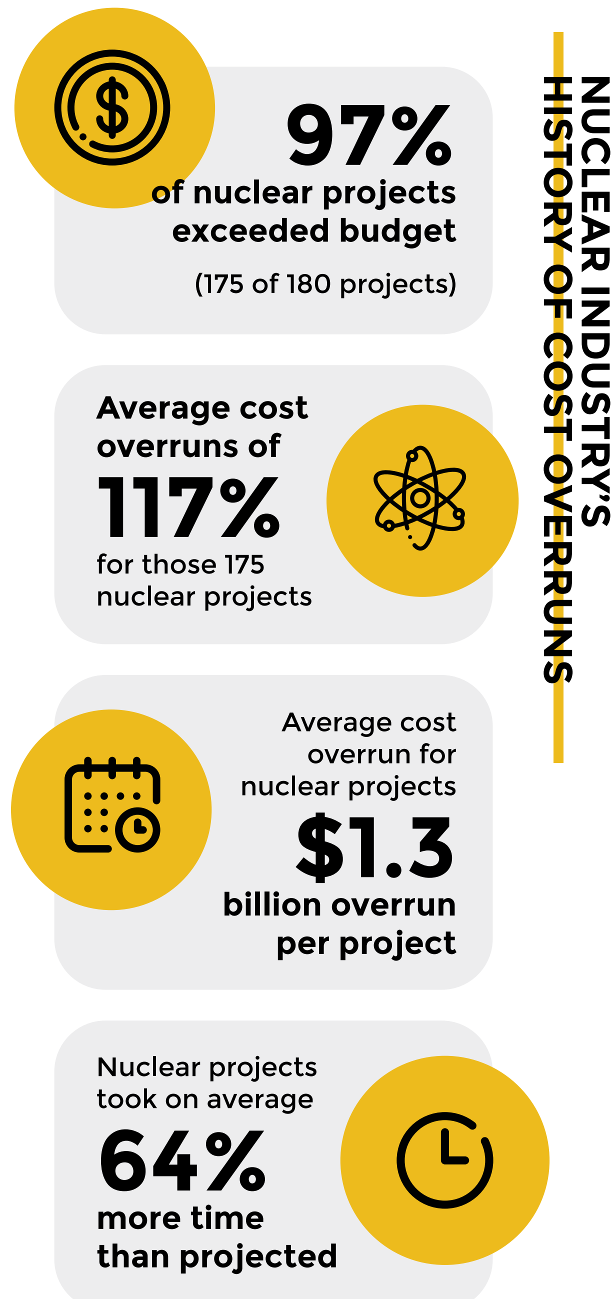

Figure 3: Cost and Time Overruns in Nuclear Plant Construction; Source: Benjamin K. Sovacool, Alex Gilbert, and Daniel Nugent, "Risk, Innovation, Electricity Infrastructure and Construction Cost Overruns: Testing Six Hypotheses," Energy 74 (September 1, 2014)

There is another reason to expect that NuScale would be more expensive: it loses out on economies of scale. A nuclear power plant that generates 1,000 MW of electricity does not require five times as much concrete or metal, nor does it employ five times as many workers as one that generates only 200 MW. If one goes by a standard rule of thumb used in cost estimates of power plants,[76] if a 1,000 MW nuclear power plant costs $5 billion (i.e., $5000/kW), an SMR with a power capacity of 200 MW would be expected to have a construction cost of $1.9 billion or around $9500/kW. Similarly, operating an SMR will also be more expensive in comparison with a large reactor due to diseconomies of scale.

Even those advocating for nuclear power and SMRs admit this problem. A nuclear engineering professor at the Massachusetts Institute of Technology, Koroush Shirvan, described this problem in an interview: “you lose so much from economy of scale…you still need operators, some plant workers, engineering management, you… have… in most cases worse fuel costs and then on the capital side… your refueling machine [is going to look] very similar and [has a lot of volume]”.[77]

We can see the underlying reasons for the expected cost increase if we compare the NuScale and the AP1000 designs. According to Westinghouse, the AP1000 design’s reactor vessel has a total weight of approximately 417 tons.[78] Now, one NuScale SMR module is designed to generate only 5.5 percent of the electricity generated by the AP1000. If one were to assume that it requires a proportional amount of metal, each NuScale unit’s reactor vessel should weigh only around 23 tons. However, NuScale’s reactor vessel weighs 260 tons according to the International Atomic Energy Agency’s Advanced Reactors Information System (ARIS).[79] Another report based on a presentation by a NuScale official reports that the reactor pressure vessel “will weigh about 340 tons (not including the core, inner vessel structures, and fuel)”.[80] Both of these figures are much greater than would be expected by scaling the power output and it shows that NuScale will spend disproportionately larger amounts of money for materials like steel and concrete.

The comparison between AP1000 and NuScale is all the more important because of the similarities in their strategies. NuScale claims that because its design is simpler and uses “fewer systems and components” it has “lower cost”.[81] Westinghouse made eerily similar claims.[82] NuScale, of course, claims to be even simpler and therefore cheaper. In 2009, a presentation by Bruce Landrey, NuScale’s Chief Marketing Officer, included a slide that tried to establish that NuScale would be cheaper by saying that the AP1000 includes four reactor coolant pumps costing $15.8 million each, whereas NuScale has none.[83] But that means that even if you include eight pumps (four per AP1000 reactor), these contribute only around $125 million of a total of around $28 billion. In other words, even if the design did not have these pumps, it would not have made a big difference to the cost of the AP1000 reactor. The bottom line is that these claims of simplicity are not sufficient to expect a low cost for the NuScale reactor design.

SMR advocates claim that the capital cost per SMR unit may decrease over time as a result of economies of serial production. There is little factual information to base any reliable estimate of the rate of learning. Rates of learning in nuclear power plant manufacturing have been extremely low at best. In both the United States and France, which have the highest numbers of nuclear reactors, more construction meant higher costs, not lower.[84] Finally, even under very optimistic assumptions about rates of learning, SMRs would have to be manufactured by the hundreds if not thousands to come down in cost to make up for their losses of economies of scale.[85]

There are thus good reasons why SMRs will cost more than large nuclear reactors on a per kW basis. This is also the conclusion from expert elicitations, which involve asking several people with significant experience in nuclear reactor manufacture for their expectations of a new technology.[86]

To summarize this long discussion, there are several reasons to expect that the NuScale reactor system, when transferred from paper to the real world, would cost much more than advertised. The cost has already doubled, even before the design has been finalized or received approval for construction by the Nuclear Regulatory Commission. Based on publicly available contract documents from UAMPS, it does appear that should the actual cost exceed projected values or financing costs be higher, then members might well be obliged to pay more.[87]

Costing Electricity from NuScale

NuScale has discussed the cost of electricity in a number of presentations and publications. As mentioned earlier, in 2015, NuScale offered a construction cost estimate of $2.895 billion or $5,078 per kilowatt at the Platts nuclear energy conference in Washington. Based on these cost estimates for construction costs, NuScale estimated the Levelized Cost of Electricity (LCOE) to be $93-$106/MWh (2015 dollars).[88] A key assumption in this LCOE estimate is that the plant is financed on a typical stockholder-owned utility basis using a mixture of debt (55 percent) and equity (45 percent) at rates of 5.5 percent and 10 percent respectively. If the project were to be constructed on a government or customer-owned utility basis, using 100 percent debt financing at just 3.5 percent, then NuScale estimated a LCOE of $72/MWh (or $77/MWh in 2019 dollars).

In 2018, NuScale claimed that because of the increased power output of 60 MW from its modified design, which has not been so far submitted to the NRC for design certification, its estimated total cost has come down, thereby lowering "the cost of the facility on a per kilowatt basis from an expected $5,000 to approximately $4,200".[89] With this construction cost estimate, NuScale claimed that it would generate electricity at a "total cost, including construction and operations, of $65 per megawatt-hour".[90]

Some utilities that have considered NuScale have come up with very different estimates for the cost of electricity. In 2018, Pacificorp estimated a cost of $94/MWh for a NuScale plant operating at a 86 percent capacity factor.[91] In its 2019 Integrated Resource Plan (IRP), Idaho Power estimated a cost of $121/MWh for a NuScale plant operating at a 90 percent capacity factor.[92]

More recently, NuScale and UAMPS have made claims about being able to supply power at even lower prices. For example, in August 2019, Idaho Falls Power General Manager Bear Prairie said that "NuScale has agreed to provide power at a maximum price of $55" (per MWh).[93] UAMPS has claimed that the target for the levelized cost of energy from the CFP project is $55 per megawatt-hour.[94] According to UAMPS, this lower cost is a result of the Department of Energy agreeing to provide UAMPS "with a New DOE Multi-Year Award in the nominal amount of $1.4 billion representing approximately 25% of the estimated Development and Construction Costs of the CFPP, spread over a period of nine years, concluding with commercial operation of the CFPP". Other financial advantages that NuScale has mentioned earlier are future federal production tax credits and limits on property taxes at the Idaho National Laboratory.[95]

In light of the increasing construction costs documented earlier, this claim about being able

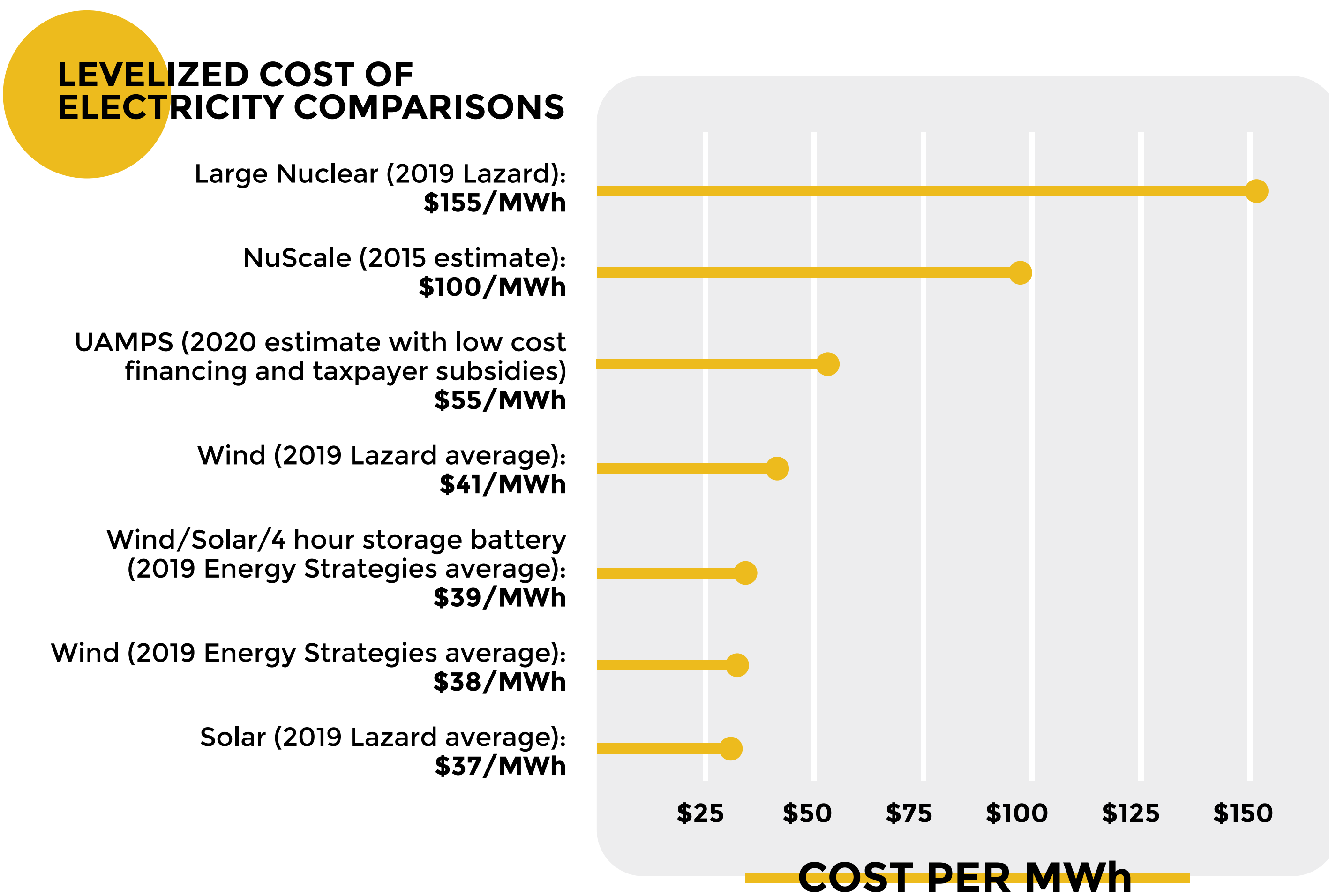

Figure 4: NuScale Reactor Cost Escalation

to generate electricity at $55 per megawatt-hour should be treated with skepticism. There is not enough transparency about how this figure has been calculated, and the assumptions utilized or other details of the calculation used to obtain this figure have not been disclosed. However, the methodology used in utility financing models is fairly standard and can be used to calculate the electricity tariff that would have to be set in order for the owner utility to be able to raise sufficient revenue to meet its annual debt obligations after accounting for all costs. This is the methodology used by the Wall Street firm Lazard, which brings out an annual report on the costs of generating electricity in the United States. Using such a model, and inputting the details provided by NuScale in its 2015 presentation, when the construction cost was estimated at $5,078/kW, we have been able to roughly reproduce the LCOE estimates of $106/MWh for a project funded with 55 percent debt at 5.5 percent and 45 percent equity at 10 percent and $72/MWh for a project entirely funded by debt at 3.5 percent were approximately reproduced. If the per unit construction cost is assumed to be $4200/kW, the LCOE for a project funded with 55 percent debt at 5.5 percent and 45 percent equity at 10 percent drops to $92.5/MWh whereas a fully debt funded project would generate electricity at around $66/MWh.

The problem is that construction costs have risen substantially since those earlier estimates. At the currently estimated "acquisition and construction" cost of $6,124 million, the cost per unit of generation capacity is roughly $8500/kW (assuming 720 MW of generation). Assuming that U.S. taxpayers pay $1,400 million of that acquisition and construction cost, the remaining $4,724 million still translates to roughly $6500/kW, or over one-and-a-half times the earlier estimate of $4200/kW. The currently quoted generation cost of $55 per megawatt-hour is inconsistent with this significant increase in construction cost; normally one would expect the generation cost to be higher than the earlier estimate of $65 per megawatt hour. Given this mismatch, it is more important than ever to transparently evaluate the economics of the proposed NuScale project and examine carefully all the assumptions made by UAMPS or NuScale in its estimates of the per megawatt-hour cost of generation.

Costs of Alternative Generation Portfolios

There is a further reason to be critically evaluate the economics of the proposed NuScale project. Even if all these assumed financial subsidies actually materialize and NuScale manages to meet all its future construction and cost targets so that the project delivers electricity at a levelized cost of $55 per megawatt-hour, there are many other power alternatives at lower cost. In 2019, the Healthy Environment Alliance of Utah (HEAL Utah) developed a number of "resource portfolios, including those that are carbon-free,… at approximately 40% ($24-28/MWh) less than" the costs then quoted by NuScale for the UAMPS project, and these will lead to substantial savings.[96]

Two of the portfolios consist purely of renewables with or without storage but generating the same number of units of electrical energy as NuScale. One portfolio with exclusively wind and solar power comes out at $38.26/MWh whereas a portfolio with wind, solar, and battery storage (Lithium based, assumed to store for 4 hours) came out at $39.04/MWh.[97] These figures are, of course, based on cost and financing assumptions, some of which end up making the portfolio more expensive than if these portfolios had been costed using the assumptions used by NuScale in its 2015 LCOE cost projections.

There is now a wealth of evidence for the far lower costs of renewables. The Wall Street firm Lazard's 2019 report on the costs of generating electricity estimated that new wind and solar energy plants would provide power at $40 per megawatt hour.[98] (In comparison, it estimated that a new nuclear plant will generate electricity at an average cost of $155 per megawatt hour.) Renewables make even more sense going forward because the costs of wind and solar power are becoming cheaper year after year; just during the last decade, they have declined by around 70 to 90 percent. Storage is also becoming cheaper. In September 2019 the city of Los Angeles contracted for a solar project that offers storage to meet demand when the sun isn't shining at $39 per megawatt hour.[99]

During the 2019 Utah General Legislative Session, municipalities served by Rocky Mountain Power were given the option of moving to 100% renewables by 2030 with a separate rate schedule as long as individual customers are able to opt out; the rationale given was that it would "meet customer demand for choice and allow utilities to replace coal generation with lower cost renewables".[100] By December 2019, 23 municipalities passed resolutions to participate, translating to approximately 37 percent of Rocky Mountain Power's total electricity sales in Utah.[101]

There is another crucial variable that will influence how costly electricity from NuScale would be: the capacity factor or load factor, which is the ratio of the actual electricity generated to the theoretical maximum that would be generated if the reactor operates at full power all the time (24 hours/day, 365 days/year). NuScale assumes that the reactor's "capacity factor will exceed 95%".[102] But this kind of high capacity factor is unlikely. It is above the average figures for the U.S. nuclear reactor fleet, which have ranged between 87 and 93 percent.[103] It is especially unlikely in the early years of a first-of-a-kind reactor.

Furthermore, such a high capacity factor is impossible to achieve as renewable energy sources become a larger fraction of the electricity being generated in the grid. This is because renewable energy plants are intermittent sources; they require the wind to be blowing or the sun to be shining. But when they are generating, they cost very little to operate since they don't need any fuel. Thus, it is economically rational to use their electricity when it is available and lower outputs from other sources.

Even NuScale recognizes this and therefore argues that its "SMRs have unique capabilities, allowing them to vary output as necessary to support system demand as capacity varies on the system from intermittent generation".[104] But when it does so, the capacity factor of nuclear reactors will naturally be lower because their output will not be the maximum possible. In one computer simulation carried out by NuScale, the power output of the reactor unit was below 70 percent of the maximum for more than 20 out of 24 hours on the chosen day, and below 50 percent of the maximum for 8 hours.[105] If deployed on a grid in conjunction with a large share of renewable energy sources, the 95 percent capacity factor assumption will simply not hold. A reduction of capacity factor from 95 percent to, say, 75 percent, would result in a roughly 20 percent increase in the cost of generating electricity from a NuScale reactor. The price of trying to operate a nuclear plant as a backup to renewables could be quite steep, stretching the credibility of those claiming this as a selling point.

Safety and Waste

Safety of its reactor design has been a chief selling point for NuScale.[106] Specific points of emphasis have been its reliance on passive safety mechanisms and small size. A smaller reactor is better in some ways because of the smaller in-core inventory of radioactive material and smaller amount of energy available for release during an accident. But NuScale is not planning to build just one small reactor; it is planning to build a group of 12 at the same site. As a result, an accident at one unit might either induce accidents at others or make it harder to take preventive actions at others. Further, if the underlying reason for the accident is a common one that affects all of the reactors, such as an earthquake, it is possible that many, or even all, units could undergo accidents. In that case, the combined radioactive inventories are sizable, even in comparison with a large reactor.

Some of these issues were observed at Japan's Fukushima Daiichi nuclear power plant. The same underlying set of causes, earthquake and Tsunami, set off meltdowns at multiple units.[107] These events at, and efforts to protect, different units interacted with each other in complex ways, affecting the progression of the events as a whole.[108] Radiation leaks from one unit made it difficult for emergency workers to approach the other units. Explosions at one reactor damaged the spent fuel pool confinement building in a co-located reactor.

There exist other safety concerns as well. Concepts like the proposed NuScale SMR design often involve shared safety systems and personnel. While this is often done to lower costs, it introduces new risks. As Karine Herviou, Director at the Institute for Radiological Protection and Nuclear Safety (IRSN, France), explains, "The use of shared systems may…introduce risk of vulnerabilities in the design, along with dependencies among the facilities".[109] Likewise, the "compact nature of SMRs may prove challenging when it comes to performing the necessary inspections, operations and maintenance, not only during the manufacturing stage, but for the entire life cycle of the SMR".[110]

NuScale is also chipping away at safety margins through various changes to design and to implementation. One set of changes to the NuScale design is documented in a presentation from May 27, 2014 by Steven M. Mirsky, NuScale's Washington DC Licensing Manager that is available on the Nuclear Regulatory Commission website.[111] Slide no. 26 includes a table that lists all the design changes and what it calls "impacts of the change". All but one entry in the column with the impacts includes "reduced cost" as one of its benefits. Clearly NuScale is making design changes to shave off every little bit from the overall cost. What that slide does not tell you is that many of these changes will reduce safety margins. For example, "Reduced depth of reactor building pool" would mean that there is less water to boil off in the event of an accident, which means that there will be less time to deal with the accident before radioactive materials are released.

Likewise, NuScale, like many other SMR vendors, has pushed the NRC to allow a smaller Emergency Planning Zone than that of a large nuclear plant.[112] NuScale has advocated for what it calls "rightsizing" this zone.[113] The primary motivation, again, is to reduce operating costs because the reactor owner is required to pay to maintain the capability of the local government and local population within the Emergency Planning Zone to respond to an accident.[114] Typical costs include installing and maintaining warning capability such as sirens, stockpiling radiation mitigating medication, and training emergency service providers so that they are prepared to implement protective actions such as the evacuation of citizens. Reducing such costs can only increase the risk of higher radiation doses to people in the areas surrounding the nuclear plant in the event of an accident.

The problems of nuclear waste—its long life and the challenge of stewarding it for hundreds of thousands of years—are well known. This will be a problem for NuScale too because just like large reactors, the proposed NuScale reactor design will produce radioactive wastes of many kinds. The problem could even be a bit more acute; proposed reactor designs like NuScale will produce more, not less, nuclear waste per unit of electricity they generate.[115] This is because more neutrons escape out of the core of a smaller nuclear reactor and because of differences in fuel management practices that are proposed. In the specific case of NuScale, it has been estimated that in addition to the roughly 60 percent increase in spent fuel generated, the volume of long-lived low and intermediate level waste generated by the SMR could be more than an order of magnitude greater for each unit of electricity when compared to a standard large light water reactor.[116]

SMR vendors typically claim that managing this waste will not be difficult. However, this view is at odds with the fact there is no demonstrated solution to dealing with the spent fuel. Although many countries have made plans of various kinds for their stockpiles of spent fuel, almost none of those plans have materialized. There is no operating repository for spent fuel and high level nuclear waste from commercial nuclear power plants anywhere in the world and this is because there are both technical and social challenges confronting proposed solutions.[117] The United States has been trying to set up a geological repository at Yucca Mountain in Nevada for decades, without success. Any community that hosts a SMR is probably also signing up to host nuclear waste for decades, perhaps even centuries.

Another environmental concern is water, which is used by most nuclear power plants for cooling. Typically, about a third of the heat generated by the fission reactions in the nuclear reactor core is converted into electrical energy. The rest of the heat has to be dispersed into the environment. Most reactors use water for this heat transfer process and in those cases the hot water that carries the excess heat is discarded into lakes, rivers, or the ocean. Water use takes two forms, withdrawals, namely the total amount of water removed from some source, and consumption (what is left over after accounting for the higher temperature water returned to the same source). Nuclear plants are known to have some of the highest water withdrawal requirements; the median value for a generic nuclear reactor in the United States is 44350 gallons per mega-watt-hour (MWh) of electricity generated and the median consumption value is 269 gallons per MWh; the corresponding figures for a combined cycle natural gas plant are 11380 and 100 gallons per MWh.[118] Renewables require little or no water because there is no heat production.

Because of the concern about water requirements in eastern Idaho, where the UAMPS project is proposed to be constructed, UAMPS has recently decided to use air cooling.[119] However, this choice implies that additional equipment—an air cooling tower and large electric fans—would have to be added, which would drive up the construction cost. Further, about 5 to 7 percent of the electricity generated by the reactor will go in just operating these fans.[120] So the power output would be smaller.

Conclusion

In August 1983, Time magazine announced: "D-day finally arrived last week for the Washington Public Power Supply System. D for default. D for debacle. With its coffers almost empty, WPPSS or Whoops, as everyone now calls the agency, formally declared that it could not repay $2.25 billion in bonds used to finance partial construction of two now abandoned nuclear power plants in Washington State. It is by far the largest municipal bond default in U.S. history, and the damage is incalculable".[121] The Washington Public Power Supply System was by no means unique. Other defaulters include Cajun Electric Power Cooperative in Louisiana and Wabash Valley Power Association in Indiana.[122] Overall, in the 1980s, electric utilities lost about $100 billion on nuclear plants that were unfinished.[123] It is no small irony that WPPSS now goes by the name of Energy Northwest, which is to be the operator of the UAMPS/NuScale SMR power plant.

The history of these losses for electric utilities, which were ultimately paid by consumers and municipal bondholders, is worth recalling when discussing the UAMPS project. When utilities embark on constructing a new reactor design such as NuScale, the risk of cost-overruns is even greater.

One response to the possibility of a construction cost increase or delay might be to say that the risk for such increases and delays will be borne by NuScale. Indeed, this is what Idaho Falls Power General Manager Bear Prairie told people in August 2019: NuScale is “going to take all that risk, and (the Department of Energy) and those entities…I’m not going to put that risk on Idaho Falls.” However, as we have described above, there are questions about such a guarantee because of the financial troubles experienced by Fluor Corporation, the company that has invested hundreds of millions into the NuScale design. In August 2019, it was reported that Fluor was going to exit fixed price contracts.[124] What repercussions this decision will have for the UAMPS project is unclear, but the earlier presumptions about NuScale assuming the risk of cost increases might have to be revisited.

With nuclear power becoming more expensive in general, the dramatic increase in the construction costs of the NuScale project, the uncertainty in the outlook for electricity demand, and renewables and storage becoming increasingly cheaper, investment in the NuScale project is simply not prudent.

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