Potential Cost Reduction in New Nuclear Deployments Based on Recent AP1000 Experience

Systems Analysis & Integration Campaign

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EXECUTIVE SUMMARY

The completion of Vogtle Units 3 and 4, despite significant cost and schedule overruns, a major bankruptcy, and a pandemic, demonstrates that the U.S. nuclear industry can still develop new supply chains, train a highly skilled workforce, and build large nuclear power plants. A common feature of megaprojects across the world are high risks of budget and schedule overruns. First-of-a-kind (FOAK) deployment of any complex technology involving a large capital investment faces significant project risks and consequent cost and schedule overruns. But these overruns are likely to decrease with more deployments through a combination of design standardization and modularization, transferring and implementing lessons learned between consecutive projects, and innovation. Recent experience with Westinghouse's giga-watt (GW) scale, modularly constructed AP1000 plants, including their domestic deployments at Vogtle Units 3 and 4, and their Chinese variants (CAP1000 and CAP1400) provides a valuable case study on how moving beyond FOAK can lead to potentially significant cost reductions as more AP1000 plants are built in the United States.

This report first gathers publicly available cost and construction timeline data for all the AP1000 plants and its variants that started construction in the United States and internationally. Eight of these plants were in the first series of builds (Vogtle and V.C. Summer in the United States and Sanmen and Haiyang in China) that concluded in 2024 with Vogtle Unit 4. A second series of 11 plants started in China in 2019—two CAP1400 plants in Shidao Bay (one complete and one under construction) and nine CAP1000s in Sanmen, Haiyang, Lianjiang, Xudabao, and Lufeng that are all under construction. An evaluation of all the timelines is performed and a comparison between series 1 and 2 in China is made to quantify schedule reductions between series. Lessons learned and challenges encountered in the first series of U.S. and Chinese builds are then summarized. Current project tracking shows promising schedule reductions in China compared to the first series built in Sanmen and Haiyang (see Figure ES-1). The second series of Chinese AP1000 projects achieved a 48% reduction in average duration from first nuclear concrete to milestone completion and a 42% reduction in average duration between milestones compared to the first series. Additionally, the corresponding variances in duration have been reduced by 60% and 46%, respectively. These are significant reductions that indicate a positive outlook for the next AP1000 deployments in the United States. Even if a portion of these reductions materialize in new U.S. deployments, it is likely that these plants become competitive with other sources of energy generation.

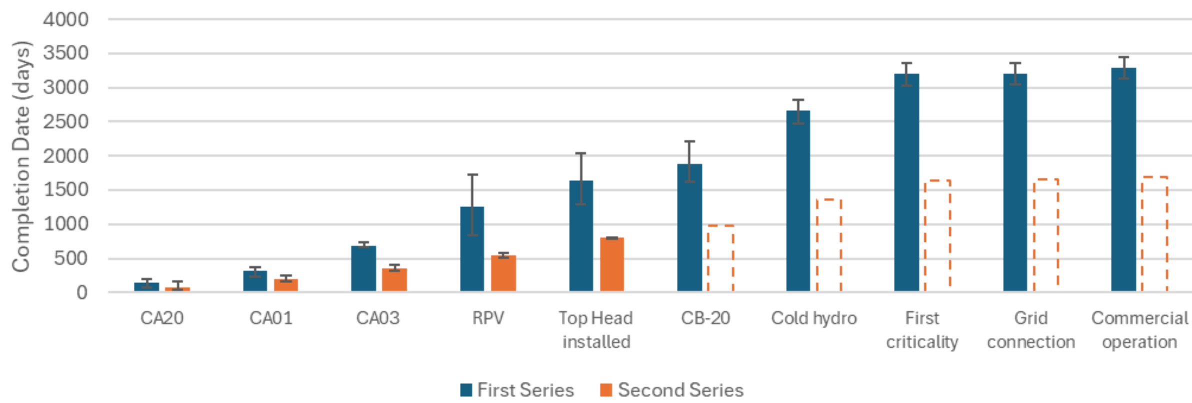

Figure ES-1. Average duration from construction start to completion for each milestone. Dotted lines represented projected duration from first nuclear concrete. Milestones on the horizontal axis are in chronological order. CA20, CA01, CA03, and CB20 are large structural modules, and their installation milestones were significant for the project.

Motivated by these data, this report evaluates the potential for cost and schedule reductions in future AP1000 plants in the United States by modeling two scenarios using a cost reduction framework developed in fiscal year 2024. In a “moderate” scenario (accounting for relative inactivity of the U.S. nuclear industry following the Vogtle construction), the second, third, and fourth two-unit AP1000 plants are projected to have an overnight capital cost of $10,000/kWe, $7,800/kWe, and $6,200/kWe, and be built in 7 years, 6 years, and 5.5 years, respectively. If an Investment Tax Credit (ITC) of 40% is applied, the second AP1000 plant Levelized Cost of Electricity (LCOE) is projected to be as low as $50/MWhre, making it very attractive to a broad range of energy markets as shown in Figure ES-2. Without any ITCs or Production Tax Credits (PTCs), AP1000s may reach an LCOE which is competitive with firm PV in some markets by the third or fourth plant. These are preliminary projections that are academic in nature, and they should not be interpreted as investor-grade predictions for the next AP1000 plants. However, they do show that cost reductions in the next AP1000s may be steep, and it may only take three to four more plants for them to produce affordable electricity. Achieving these reductions requires consistent building without too large a gap between projects, and that considerable and intentional efforts are made by owners and developers to gather lessons learned and apply these lessons in future projects.

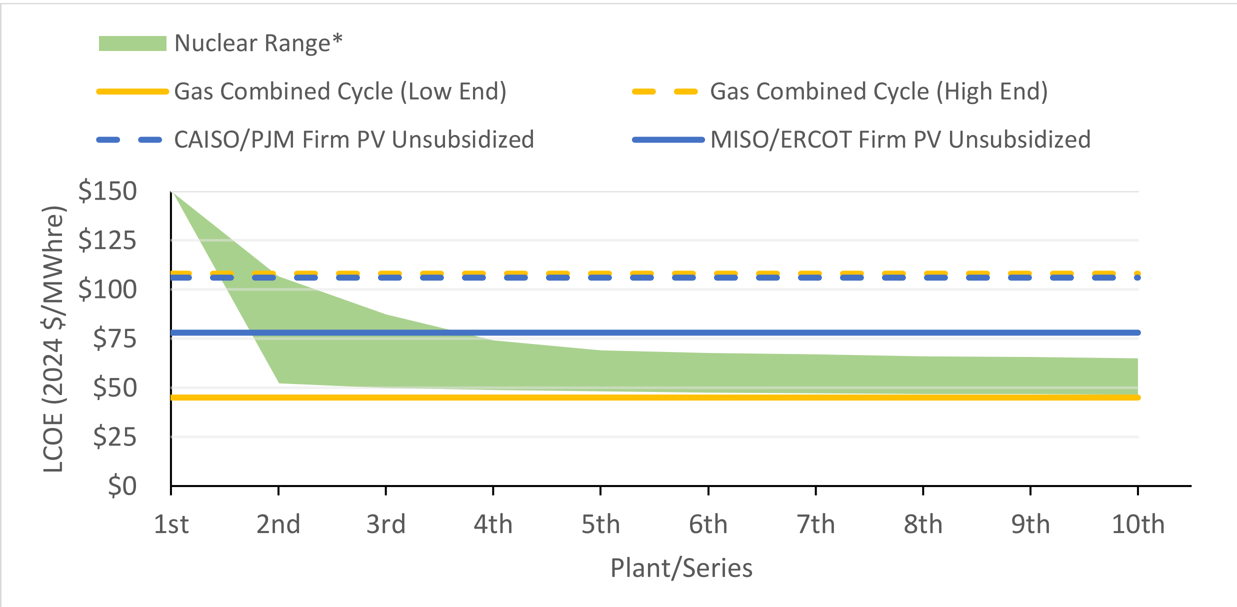

Figure ES-2. Evolution of AP1000 LCOE as more plants are built and a comparison with other, equivalent energy sources. Key: *The nuclear range is between a 40% ITC (lower bound) and without any ITC (upper bound). CAISO stands for California Independent System Operator (ISO), PJM stands for Pennsylvania-New Jersey-Maryland Interconnection, MISO stands for Midcontinent ISO, and ERCOT stands for Electric Reliability Council of Texas.

In addition to quantifying the potential cost reductions in the next few AP1000 plants in the United States, this study also identifies some barriers and potential solutions to achieving these cost reductions. An immediate barrier is the reluctance in financial investment in the next plant due to the perceived financial risk. This study attempts to address this reluctance by showing that the financial risks for the next few builds might be much smaller than for the FOAK plant, as the overrun risks may be substantially lower. Other barriers include the lack of availability of a skilled workforce and supply chain needed to rapidly and significantly expand nuclear construction. Addressing these barriers through innovation, and importantly, making the investments to gather and implement lessons learned between consecutive projects will not only help achieve the projected cost reductions in the next AP1000 plants but also help reduce the risk of overruns for other advanced reactors scheduled to be built in the United States.

ACKNOWLEDGMENTS

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ACRONYMS

ACTI	advanced construction technologies initiative
CCGT	combined cycle gas turbines
CDF	core damage frequency
CFR	Code of Federal Regulations
CNNC	China National Nuclear Corporation
CNY	Chinese yuan
COL	Combined Construction and Operating License
DCD	design control document
DOE	U.S. Department of Energy
EPC	engineering, procurement, and construction
FILT	first in a long time
FOAK	first of a kind
IAEA	International Atomic Energy Agency
INL	Idaho National Laboratory
IPD	integrated project delivery
ISO	independent system operator
ITC	investment tax credits
LAR	license amendment requests
LCOE	levelized cost of electricity
LOCA	loss of coolant accident
NOAK	nth of a kind
NRC	U.S. Nuclear Regulatory Commission
NRIC	National Reactor Innovation Center
NSSS	nuclear steam supply system
OCC	overnight capital cost
PTC	production tax credits
PV	photovoltaics
PWR	pressurized-water reactor
PRIS	Power Reactor Information System
QA	quality assurance
QC	quality control
RCP	reactor coolant pump
RPV	reactor pressure vessel

SMR	small modular reactor
SPIC	State Power Investment Corporation
USD	U.S. dollar
WE-FOAK	well-executed first of a kind

POTENTIAL COST REDUCTION IN NEW NUCLEAR DEPLOYMENTS BASED ON RECENT AP1000 EXPERIENCE

1. INTRODUCTION

Due to the long hiatus of nuclear construction in the United States, there was significant attention on the construction progress of the AP1000 power plants in South Carolina (i.e., V.C. Summer Units 2 and 3) and Georgia (i.e., Vogtle Units 3 and 4). Since Vogtle Units 3 and 4 have entered commercial operation, it would be appropriate to reflect on the completed project and the potential for the expanded deployment of AP1000s and other new nuclear plants in the United States.

This work has been motivated by several reasons. First is the completion of the initial domestic AP1000 plants, Vogtle Units 3 and 4, which have been long fraught with challenges, controllable and uncontrollable, causing considerable schedule delays and cost overruns. However, even with the cost and schedule overruns, completing this construction can still be considered a success, providing 2200 MW of reliable baseload power for 80 years. Each of the lessons learned from these projects will be important to future builds of AP1000s and advanced reactors, making them important components to support a growing nuclear demand. Second, significant schedule reductions are being seen in the second series of AP1000 (and its Chinese variant, CAP1000) plants in China. The fact that the first series of Chinese AP1000 plants took almost the same amount of time as Vogtle makes these reductions even more exciting and offers a practical case study for analyzing future cost reductions in the United States. Third, the significant attention paid to first-of-a-kind (FOAK) costs of AP1000s necessitates a forward-thinking mindset to project potential learnings and cost reductions for future AP1000 builds. Megaprojects across the world are over budget and over schedule (Flyvbjerg, Bruzelius, & Rothengatter, 2003), and FOAK deployment of any complex technology involving a large capital investment faces significant project risks and consequent cost and schedule overruns. But these overruns will very likely decrease with more deployments through a mix of design standardization, transferring lessons learned between subsequent projects, enabling learning-by-doing, and innovation. This report's goal is to try to change the narrative around the cost of new nuclear in the United States, moving from solely focusing on the FOAK costs to looking at the observed trends in cost and schedule reductions across AP1000 deployments and using these trends to project potential cost reductions as more AP1000s are built in the United States.

The remainder of this report is organized as follows:

- Section 2 provides an overview of the AP1000 design, its improvements over traditional light-water reactor plants, and its modular construction process while maintaining economies of scale
- Section 3 summarizes AP1000 deployments in the United States and China and their corresponding lessons learned for future projects
- Section 4 provides an analytical evaluation of the schedules and costs of these deployments
- Section 5 leverages this evaluation to project cost reductions in future U.S. AP1000 builds
- Section 6 identifies some solutions that may help fulfill these cost reductions for both AP1000s and advanced reactors
- Section 7 provides a summary and key takeaways from this study.

2. AP1000 NUCLEAR POWER PLANT OVERVIEW

The AP1000 is a two-loop, modularly constructed 1.1 GWe nuclear power plant design developed by Westinghouse Electric Company (WEC). It is a pressurized water reactor (PWR) that incorporates passive safety features that rely on natural forces like gravity, natural circulation, and compressed gas to ensure safety in the event of an emergency. These advanced passive features are where the design gets its name: Advanced Passive 1000 or AP1000. This section serves as a brief overview and description of the AP1000, including discussion on design, licensing, and modular construction methodology.

2.1 Design Overview

The AP1000 was designed to improve the passive response of the plant, so that the plant will remain safe during an accident (e.g., a loss of coolant accident [LOCA]) without the need of offsite power, reducing the need for active components, such as pumps, diesel generators, and extensive piping. These systems provide core cooling, maintain containment integrity, and rapidly reduce reactor pressure during certain accident scenarios. The true testament to the improved passive design is reflected in the core damage frequency (CDF)—the likelihood of an accident scenario resulting in damage to the fuel—which is an extremely low value of 5×10^{-7} per year (Westinghouse Electric Company, 2007). That is 200 times lower than the U.S. Nuclear Regulatory Commission (NRC) requirement (1×10^{-4}) and 20 times lower than the International Atomic Energy Agency (IAEA) safety target (1×10^{-5}) for future plants (World Nuclear Association, 2021).

As shown in Figure 1, the primary coolant system in the AP1000 consists of two loops, each with two reactor coolant pumps, a steam generator, and associated piping, all of which are designed to help enable passive safety. The AP1000 design also incorporates advanced instrumentation and control systems to enhance operational safety and efficiency, enabling improved monitoring, diagnostics, and control capabilities.

In addition to the passive safety features and modern design attributes, the design aims to provide economic benefits through improved constructability by incorporating a simpler design, modular construction, reduced components, and a smaller site footprint (Westinghouse Electric Company, 2007).

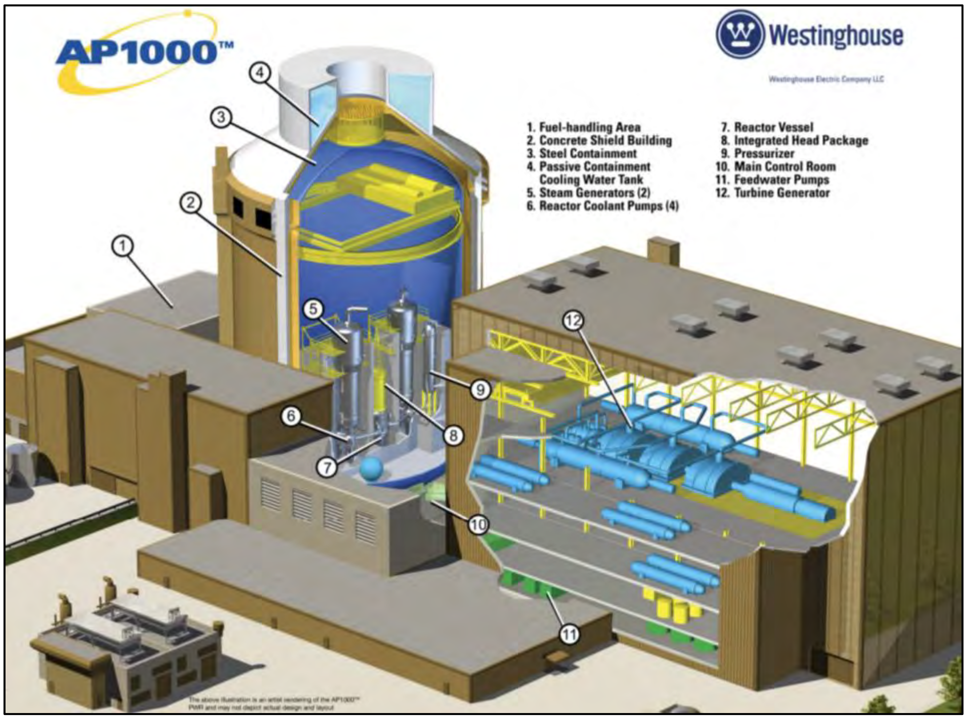

Figure 1. The Westinghouse AP1000 (U.S. NRC, 2011).

The AP1000 Nuclear Steam Supply System (NSSS) incorporates numerous proven Generation II pressurized-water-reactor components—specifically those from the two-loop Combustion Engineering PWR NSSS and the three- and four-loop Westinghouse PWR NSSSs—alongside new passive safety systems. Combining NSSS hardware that has accrued tens of effective full-power years (or more) of operating experience with rigorously qualified, innovative passive-safety features has enabled first-of-a-kind AP1000 units to achieve capacity-factor performance on par with the most reliable light-water reactors during their initial years of operation.

2.1.1 Standard Plant Design

The Westinghouse AP1000 is considered one of the most standardized GEN III+ nuclear reactors in the world, featuring simplified design, passive safety, and modular construction intended to reduce cost and shorten construction time, while minimizing the licensing process for deployment of the same standardized reactor system in different locations.

According to the AP1000 Design Control Document (DCD), the design has accounted for a wide range of site parameters at most potential locations in the United States, enabling safe operation with minimal need for site-specific design modifications. The AP1000 includes standard design capabilities that cover 70 to 80 percent of possible U.S. siting location requirements, accommodating local variations in geography, meteorology, flooding, and seismicity requirements (Westinghouse Electric Company, LLC., 2011). While some site-specific changes may be necessary to comply with the local requirements, these changes are expected to be minimal.

Other changes may be needed to meet the regulatory requirements of a specific country; however, the standardized design should simplify the adaptation process necessary to meet any local regulatory and licensing requirements. A streamlined licensing process is considered a key attribute for reducing costs for successive deployments.

2.1.2 Licensing and Regulation

The U.S. NRC plays a pivotal role in design, construction, deployment, and operation of nuclear reactors in the United States. The NRC follows a rigorous review process at every step from nuclear plant site selection to design, construction, and operation review and approval. Such reviews are critical in ensuring safe design and operation of any nuclear facilities. The NRC regulates this process through a rigorous and structured Title 10 of *Code of Federal Regulations* (10 CFR). The 10 CFR framework includes several “parts,” each covering specific regulatory areas to ensure safety, security, environmental protection, and public safety. For example, under 10 CFR Part 50, an applicant seeking to obtain approval for construction and operation of a nuclear power plant would require a separate approval for construction and operating license. The 10 CFR Part 52 is designed to streamline the process by combining both construction and operation in a single approval process, thus simplifying the entire process and reducing the review process time and cost. The details regarding 10 CFR and various parts can be found on the NRC website (U.S. NRC, 2025).

For a company interested in deploying a nuclear reactor on a new site, obtaining the early site permit can be a step in this process. This assesses the suitability of the site for nuclear power plants and allows an applicant to obtain approval for a reactor site before committing to any specific reactor design.

Westinghouse submitted the AP1000 standard design certification application to the NRC in March 2002 and received approval in 2006. Westinghouse submitted amendments to the DCD, with the latest version, Revision 19, being approved in 2011. Southern Company used Revision 19 of the DCD for their license of Vogtle Units 3 and 4 with over 180 license amendment requests (LARs) by the time the project was completed.

2.2 AP1000 Construction Methodology

The AP1000 was designed to enable an expedited construction process by requiring less materials and a smaller footprint. Most notable, however, is the use of modular construction techniques to enable rapid assembly and minimize onsite fabrication. Open top construction is another feature of the AP1000 design for construction, allowing for top-side access that enables the use of overhead cranes to lift the heavy modules and components into place. All of these, in theory, provide a construction process that aims to reduce the overall project time.

2.2.1 Modular Construction

A major facet of the AP1000 design centers around the method of modular construction. Modular construction is the process of producing standardized and prefabricated major components offsite, transporting them, and assembling them onsite. Modular construction is touted as having many benefits, such as improvements to quality, productivity, and coordination—all of which can help reduce total project cost with some studies estimating up to 22% (Lim, Ling, Tan, Chong, & Thurairajah, 2022). More often, modular construction is associated with higher procurement and direct costs but reduced financing costs through schedule acceleration (Stewart, Gregory, & Shirvan, 2022).

Modular construction can enhance productivity by allowing parallel construction activities; while modules are being fabricated off-site, site preparation and foundational work can progress simultaneously. This overlap shortens the overall construction timeline.

However, there are challenges associated with modular construction that include onsite storage, high upfront payments, logistical issues, variability management challenges, the need for multiple stakeholder cooperation, supply chain management, and late commitment (Wuni & Shen, 2020) (Hu, Chong, & Wang, 2019). While these challenges can introduce new complexities to the construction process, modular construction has the potential to significantly reduce costs. Successful implementation necessitates substantial knowledge, experience, and upfront planning to fully realize its benefits. As learning is transferred to successive deployments, better returns and cost reductions can be anticipated.

As shown in Figure 2, the AP1000's modular design consists of hundreds of modules and thousands of submodules. These modules are categorized into structural, piping, mechanical equipment, and electrical equipment.

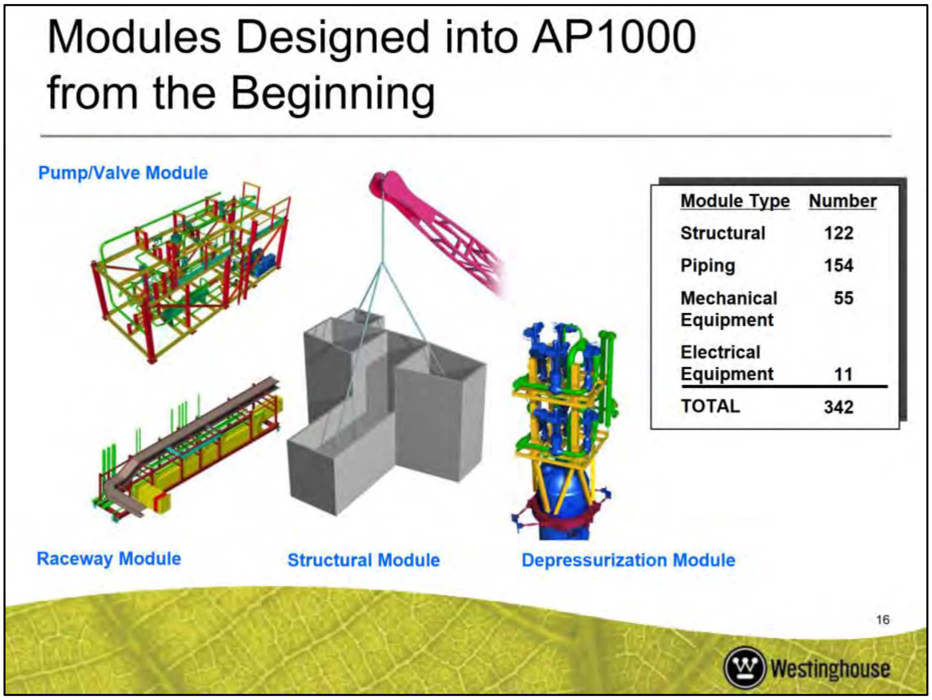

Figure 2. AP1000 modules, reproduced from (Westinghouse Electric Company, 2009).

There are several main modules that are commonly referred to in the media and are used as milestones for project completion. These tend to be the larger structural modules, such as:

- **CA01**: steam generator and refueling canal inside containment composite wall module
- **CA02 and CA03**: In-containment refueling water storage tank
- **CA04**: reactor vessel cavity/reactor coolant drain tank inside containment composite wall module
- **CA05**: chemical and volume control system, access tunnels, and walls
- **CA20**: auxiliary building module
- **CB20:** containment water tank (located on roof of containment for passive cooling).

While this is far from an exhaustive list, the modules listed are considered major milestones in the construction project due to their size and complexity. The complexity and size of these modules can be seen in Figure 3, showcasing the CA01 module that weighs over 2.3 million pounds during the lift. Many of these modules will be referenced later in this report as project tracking milestones when performing quantitative construction analysis, such as in Section 4.

Figure 3. CA01 module. Figures adapted from (Westinghouse Electric Company, 2014) and (World Nuclear News, 2024).

2.2.2 Open Top Construction

As can be seen in Figure 3, the AP1000 utilizes an open-top construction methodology, which is particularly effective in modular construction, as many of the larger components and modules are lowered into place using cranes. Open-top construction can help accelerate the process and improve efficiency, safety, and quality control. Efficiency is also improved by allowing multiple activities and sections of the plant to be constructed simultaneously in various locations, dropped into place, and then assembled. Safety is improved by reducing onsite scaffolding and lowering the risk of falls and injury. Last, quality control can be improved by enabling better access while fabricating components, maintaining constant control of the fabrication environment, and providing easier access for inspection.

Although open-top construction has many benefits, it does not come without its disadvantages and is debated as a potential source of delays (Kwak & Lee., 2024). One main disadvantage is the strict sequence of installations that are required for lifting and placing components. Supply chain delays can significantly impact these installations and delay the entire project. Table 1 summarizes the advantages and potential disadvantages.

Table 1. Advantages and disadvantages of open-top construction.

Advantages	Disadvantages
Ease of access	Weather dependency and delays due to lack of covering
Large cranes and lifting equipment	Safety and lifting concerns (e.g., dropped objects)
Easier installation of large components	Contamination risks
Simplified logistics for heavy materials	No climate control
Flexibility in construction sequencing	Sequence of installation is critical

2.2.3 Construction Timeline

Construction phases of the AP1000 follow a typical timeline for nuclear power plant construction: site preparation, excavation, nuclear construction, commissioning, and startup. This process is expected to span several years. Figure 4 shows the expected construction timeline from a research paper published in 2006, about 1 year before any orders were placed for the AP1000 (Gaio, 2006). In this publication, the AP1000 was expected to take a total of 5 years (60 months), beginning at the time the plant order is confirmed and ending with the commencement of commercial operation. The construction phase (starting from first nuclear concrete) to commercial operation was estimated to take a total of 42 months or 3.5 years.

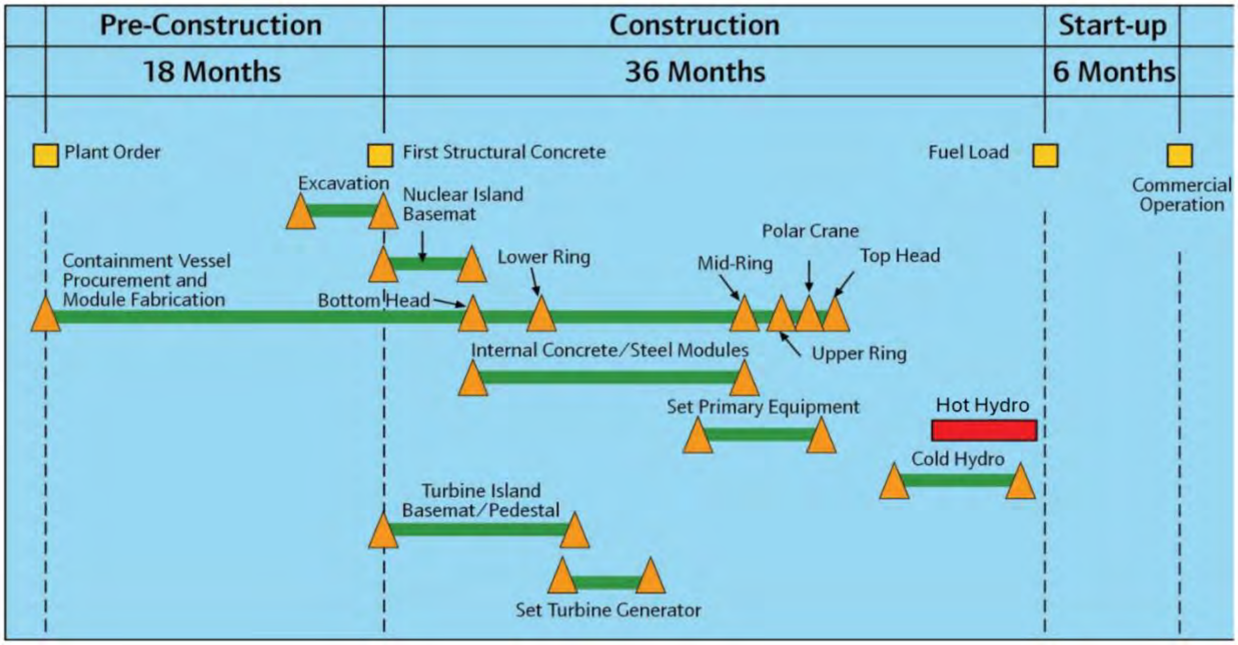

Figure 4. Estimated original AP1000 construction scenario as discussed in (Gaio, 2006).

As can be seen in Figure 5, the timeline consists of three main phases of preconstruction, construction, and then startup. Preconstruction consists mainly of procurement and fabrication of the modules that will be assembled during the construction phase. Excavation is also included in the preconstruction phase. After the excavation is completed, the process of pouring structural concrete begins, commonly referred to as “first nuclear concrete.” Although the project is well underway and has been ongoing for more than a year at this point, the pouring of concrete is considered the official start of construction and is referred to as such throughout the remainder of this report. Once construction is started, the modules that make up the AP1000 continue to be built and assembled onsite. The construction phase ends with the successful completion of the cold and hot hydrostatic tests, which ensure the successful construction of the pressurized piping and equipment within the plant. Start-up is the last phase and ends with the beginning of commercial operation.

3. RECENT AP1000 CONSTRUCTION PROJECTS

Due to the AP1000’s design advantages and passive safety features, it was selected for several potential projects in the late 2000s during the nuclear renaissance for multi-unit plant deployments in China and the United States. Among the list of potential sites, four locations were selected for the first series of construction: Sanmen (China), Haiyang (China), V.C. Summer (United States), and Vogtle (United States). The construction of these AP1000 reactors has yielded valuable insights into the challenges and opportunities of deploying new-generation nuclear power plants.

The first series of projects faced significant challenges, including regulatory hurdles, supply chain issues, and financial difficulties, but the completion of this first series provides a valuable baseline and lessons learned for future improvements. In contrast, the second series of Chinese projects, including those at Lianjiang, Xudabao, Sanmen 3 and 4, and Haiyang 3 and 4 have demonstrated significant advancements in cost and schedule management. By analyzing these case studies, this section identifies key lessons that can inform future AP1000 builds and other next-generation nuclear projects.

Throughout this section and the sections that follow, a variety of costs will be referenced from multiple sources. When discussing costs, it is important to note the dollar year associated with value. Products increase in cost, or escalate, with time due to a multiplicity of reasons, one of which being the change in price for key inputs. A piece of equipment may cost $10 in 2010, but cost $15 in 2020 because its components increase in cost by $5 (resulting in an escalation rate of 50%). Consequently, values across time should not be treated equivalently and when costs are directly compared; they should be escalated into the same dollar year. In the following text, where costs are reported in a specific dollar year by the source, the dollar year is included. In some instances, a dollar year was not available for the sources, and this is indicated. When necessary for comparisons, costs are escalated into the same dollar year, otherwise the values reported by the source is left unescalated.

3.1 Vogtle Units 3 and 4

Vogtle Units 3 and 4 are the first new U.S. reactors to start construction in decades and the first AP1000 units built in the United States. The project at Plant Vogtle in Waynesboro, Georgia, (see Figure 5) was intended as the FOAK deployment of the AP1000 in the United States. Construction began in 2013 (first nuclear concrete for Unit 3 in March 2013) with an original target to have both units online by 2016–2017. The initial certified capital cost for the two units was approximately $14 billion (reported in 2012 USD) (Amy, 2024). However, Vogtle 3 and 4 encountered severe delays and cost escalations. Unit 3 achieved commercial operation only in July 2023, and Unit 4 followed in April 2024, roughly 7 years behind schedule. The project's total cost to the utility owners ultimately reached approximately $31 billion (reported in 2024 USD) (excluding financing, after credits from contractor settlements), more than double the original estimate (without adjusting for inflation). Including payments by Westinghouse during its bankruptcy exit, the overall cost approached $35 billion (in 2023 USD as reported by Shirvan, 2024).

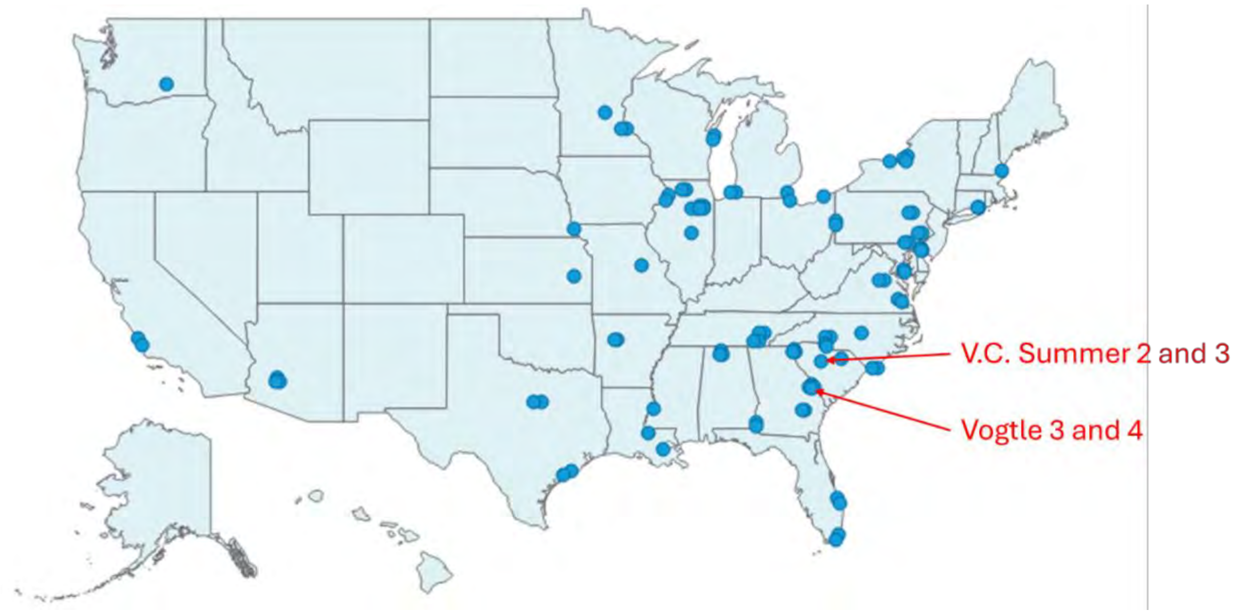

Figure 5. U.S. AP1000 locations among all operating commercial nuclear reactor locations. Map adapted from (Nuclear Energy Institute, 2024)

Several factors contributed to Vogtle's difficulties, which have been documented widely in various reports and most recently in the 2024 version of the *Pathways to Commercial Liftoff: Advanced Nuclear* report, referred to here as *DOE Liftoff Report* (Department of Energy, 2024). Broadly, these challenges can be categorized into FOAK-related, and first-in-a-long-time (FILT)-related. The FOAK issues include starting construction with an incomplete design, developing a supply chain for this specific design, dealing with constructability issues for the FOAK design, etc. The FILT issues are a direct result of building a nuclear plant in the United States after a decades-long hiatus. This includes compensating for the loss of experience by rebuilding a skilled workforce of engineers and craft labor and the loss of the supply chain by starting up (or repurposing) factories for the structural modules and other components. Many components had to be sourced globally, and onsite module fabrication faced quality problems. For example, the U.S. supply chain for AP1000 involved dozens of suppliers worldwide, leading to fabrication delays. FOAK issues with the AP1000's novel design (such as its steel containment vessel, modular construction approach, and module fabrication quality) required significant rework. By 2021, estimated costs had risen to \$28–34 billion (Georgia Power, 2009-2024), still shy of the resulting \$35 billion (in 2023 USD as reported by Shirvan, 2024)[a].

The project also had several unique challenges that inflated costs including incomplete design at start, schedule delays, and construction management issues as noted by multiple independent assessments (World Nuclear News, 2022) (Shirvan, 2022) (Shirvan, 2024).

From a regulatory standpoint, the AP1000 plant was the first to fully complete the single-step licensing process under 10 CFR Part 52. The design certification took two years, and even then, the combined construction and operating license (COL) along with numerous license amendments and inspections added time and complexity due to the incomplete design. The use of 10 CFR Part 52 requires a complete and finalized design before construction begins, unlike the previous two-step process under 10 CFR Part 50. Any design change required a LAR, inspections, and final approval by the NRC. Due to

[a] Costs reported in the media and other publications may differ from costs reported here, depending on dollar year reported and assumptions in cost escalation methodology.

updates after submitting the COL, Vogtle Units 3 and 4 required over 180 LARs by the time the project was complete.

A major disruption occurred as a result of Westinghouse filing for Chapter 11 bankruptcy in 2017, halting work until Southern Company and new contractor Bechtel took over to manage the project (World Nuclear News, 2022). After 2017, project stakeholders implemented several strategies to stabilize Vogtle. The project schedule was re-baselined, and more rigorous oversight was provided by the Georgia Public Service Commission (including frequent monitoring reports). The owners also negotiated a settlement wherein Westinghouse's parent (i.e., Toshiba) paid $3.7 billion (reported in 2017 USD) to Vogtle's owners to remove themselves from the project (Kageyama, 2017).

In summary, Vogtle 3 and 4 experienced FOAK challenges of nuclear construction in a new regulatory and industrial environment, resulting in high capital cost ($11,000/kW of unescalated, realized overnight capital cost [OCC] as reported in Shirvan (2024)), schedule slips, and significant uncertainty. Still, the project's eventual completion in 2023–2024 provides a valuable baseline. The cost and schedule of future AP1000 builds is expected to improve upon this baseline, as many one-time issues (e.g., design finalization, initial licensing, first-time component fabrication) will have been resolved (World Nuclear News, 2022) (Shirvan, 2022) (Shirvan, 2024) and if lessons learned from Vogtle are implemented in future projects.

3.2 V.C. Summer Units 2 and 3

V.C Summer Units 2 and 3 were intended to be among the first new U.S. reactors in decades, and the first AP1000 units built in South Carolina. V.C. Summer Unit 2 was the first AP1000 to start construction in the United States, pouring first nuclear concrete in March 2013 with Unit 3 following closely behind in November 2013. The units were to come online by 2017–2018. The initial cost was estimated to be $9.8 billion (dollar year not reported) under a fixed-price contract (World Nuclear News, 2016), meaning that the contractor (i.e., Westinghouse) would be responsible for absorbing overruns. However, similar to Vogtle 3 and 4, V.C. Summer 2 and 3 faced severe delays and cost escalations.

Ultimately, in 2017, after several years of construction delays and overruns, over $9 billion had been spent on the project, and finishing the project was expected to continue until 2023 and could reach $24 billion (McLeod, 2017). The situation worsened when Westinghouse's Chapter 11 bankruptcy delayed construction and nullified the fixed-price contract. Despite efforts to find a solution, the owners (SCANA and Santee Cooper) decided to abandon the project in August 2017, citing financial and logistical challenges (Patel, 2017).

Several factors contributed to V.C. Summer's difficulties including extensive regulatory and licensing processes, an incomplete design at the start, construction management issues, low worker morale, supply chain shortfalls, and quality problems with module fabrication (World Nuclear News, 2017) (Bechtel, 2016).

In summary, V.C. Summer 2 and 3 experienced the challenges of FOAK nuclear construction, resulting in high capital costs, schedule slips, and significant uncertainty. Unlike Vogtle, which eventually saw completion, the V.C. Summer project was abandoned. However, recent discussions surrounding the potential restart of the project (World Nuclear News, 2025) highlight the value of even incomplete nuclear power plant assets. With rising interest in nuclear energy more broadly, stakeholders are recognizing the AP1000 FOAK challenges have been addressed through the completion of Vogtle 3 and 4, underlying the potential value of new deployment.

3.3 Chinese AP1000 Deployments

This section provides a summary of the completed and ongoing deployments of the Chinese AP1000, CAP1000, and CAP1400 nuclear reactors. The specific projects covered include the projects located at Sanmen, Haiyang, Lianjiang, Xudabao, and the CAP1400 demonstration project at Shidao Bay. These projects are visually represented and highlighted on the map shown in Figure 6, which aids in understanding their geographical distribution and status.

Table 2 provides detailed information on each deployment, matching the highlighted colors used in Figure 6. This includes the power capacities of the reactors, the first nuclear concrete date, and relevant reactor model information. The Chinese units are managed by project control groups, detailed in Table 2, which effectively act as the Engineering Procurement and Construction (EPC) contractors. The project control groups are China National Nuclear Corporation (CNNC), State Power Investment Corporation (SPIC), China Huaneng Group (known as Huaneng), Datang International Power Generational Company (known as Datang), and China General Nuclear.

Figure 6. Chinese AP1000 and CAP1400 construction sites. Adapted from (World Nuclear Association, 2025).

Table 2. Chinese AP1000 and CAP1400 unit details (sorted by first nuclear concrete poured date).

Series no.	Unit	Project control	Model	Net capacity	First nuclear concrete date	Completion date
Series I	Sanmen 1	CNNC	AP1000	1157 MW	4/19/2009	9/21/2018
	Haiyang 1	SPIC	AP1000	1170 MW	9/24/2009	10/22/2018
	Sanmen 2	CNNC	AP1000	1157 MW	12/15/2009	11/5/2018
	Haiyang 2	SPIC	AP1000	1170 MW	6/20/2010	1/9/2019

Series no.	Unit	Project control	Model	Net capacity	First nuclear concrete date	Completion date
Series II	Shidao Bay II-1	SPIC & Huaneng	CAP1400	1500 MW	6/19/2019	11/4/2024
	Shidao Bay II-2	Huaneng & CNNC	CAP1400	1500 MW	4/21/2020	2025 (expected)
	Sanmen 3	CNNC	CAP1000	1163 MW	6/28/2022	2027 (expected)
	Haiyang 3	SPIC	CAP1000	1161 MW	7/7/2022	2027 (expected)
	Sanmen 4	CNNC	CAP1000	1163 MW	3/22/2023	2028 (expected)
	Haiyang 4	SPIC	CAP1000	1161 MW	4/22/2023	2027 (expected)
	Lianjiang 1	SPIC	CAP1000	1161 MW	9/27/2023	2028 (expected)
	Xudabao 1	CNNC & Datang	CAP1000	1000 MW	11/3/2023	2028 (expected)
	Lianjiang 2	SPIC	CAP1000	1161 MW	4/29/2024	2029 (expected)
	Xudabao 2	CNNC & Datang	CAP1000	1000 MW	7/17/2024	2029 (expected)
	Lufeng 1	CNG	CAP1000	1161 MW	2/24/2025	2029 (expected)

3.3.1 First Series: Sanmen and Haiyang

China’s Sanmen Nuclear Power Station Unit 1 in Zhejiang Province was the world’s first AP1000 reactor to start construction and the first AP1000 reactor to enter commercial operation in 2018. Similar timelines were observed for three more AP1000 reactors: Sanmen Unit 2, and Haiyang Units 1 and 2 built concurrently in Haiyang city, Shandong Province.

The first pair of AP1000 reactors in Sanmen were estimated to cost CNY 32.4 billion yuan in 2008 but later estimates in 2013 gave figures of CNY 40.1 billion ($6.12 billion USD-2013). However, the final costs exceeded initial estimates due to various factors, including design modifications, equipment cost escalations, delays in response to evolving safety standards following the Fukushima accident, and changes in import taxation policies. The final sum was CNY 10 billion yuan higher ($1.46 billion USD-2018) than the 2013’s estimation, resulting in a total of CNY 50 billion ($7.3B USD-2018) (Dalton, 2018).

Similar to the Vogtle and V.C. Summer projects, Sanmen and Haiyang encountered several significant FOAK challenges. Design and regulatory delays emerged due to multiple necessary revisions needed to meet evolving safety standards and rigorous regulatory reviews, significantly impacting schedules (IEEE Spectrum, 2018). Supply chain difficulties, particularly regarding specialized components such as reactor coolant pumps, required extensive redesign and retesting, further contributing to project delays (POWER Magazine, 2018). Additionally, project complexities, specifically integrating modular construction techniques and workforce coordination, highlighted the need for more robust practices (Modern Power Systems, 2017).

Despite these challenges, the Sanmen and Haiyang projects offered critical learnings and positive outcomes. They facilitated valuable knowledge transfer, significantly benefiting subsequent AP1000 projects through improved efficiency and reduced construction timelines. Technologically, the successful operationalization and testing of passive safety systems validated the AP1000's innovative design, thereby advancing nuclear reactor safety. Economically, the experiences indicated that, despite initial overruns, nuclear power could remain competitive compared to alternative energy sources, especially with the application of lessons learned (World Nuclear News, 2022).

3.3.2 Second Series: Chinese Expanded Deployment

Unlike the United States, China proceeded with realizing cost and schedule reductions, beginning construction on a second series of AP1000 plants in four locations: Sanmen, Haiyang, Lianjiang, and Xudabao. The second series of construction started in 2022 at Sanmen and is ongoing.

The second series of Chinese expanded deployment changed all plans for future AP1000 units to CAP1000 units, which is the localized variant of the U.S. AP1000 design. While both reactor designs share fundamental technologies, including passive safety features, modular construction, and similar core designs, the CAP1000 involves significant localization efforts and adaptations tailored to Chinese regulatory environment, manufacturing capabilities, and construction practices. Specially, the CAP1000 emphasizes increased use of domestically sourced components and equipment, aiming to reduce reliance on foreign suppliers and improve cost efficiency for China's nuclear sector (World Nuclear Association, 2025).

At the Sanmen Nuclear Power Station in Zhejiang Province, following the initial AP1000 reactors that have been operational since 2018, two additional CAP1000 units (Units 3 and 4) commenced construction activities in June 2022 and March 2023, respectively.

In parallel, the Haiyang Nuclear Power Plant in Shandong Province is similarly expanding with two additional CAP1000 units (Units 3 and 4), approved simultaneously in April 2022. Construction started in July 2022 and April 2023, and the expected cost is approximately CNY 40.0 billion ($5.9 billion USD in May 2022) (Shanghai Nuclear Engineering Research and Design Institute, 2022).

The Lianjiang Nuclear Power Plant, situated in Guangdong Province, is a newer development envisioned to accommodate six CAP1000 reactors when completed. As its initial phase, construction of Units 1 and 2 was authorized in September 2022. Initial concrete pouring commenced in September 2023 for Unit 1 and in April 2024 for Unit 2. The cost of the two units has been estimated to be around CNY 37.8 billion ($5.6 billion USD in June 2022) (Dalton, 2023). Commercial operation for Unit 1 is expected in 2028.

At Xudabao Nuclear Power Plant in Liaoning Province, the project initially planned six CAP1000 reactors; however, it was later modified to include two VVER-1200 reactors alongside two CAP1000 reactors (i.e., Units 1 and 2). Constructing these units began in November 2023 for Unit 1 and July 2024 for Unit 2. The cost estimate for Units 1 and 2 is approximately $6.6 billion USD (World Nuclear News, 2024).

The Lufeng Nuclear Power Plant in Guangdong Province encompasses four CAP1000 units (Units 1–4), approved by China's National Development and Reform Commission in September 2014. While the approval for Lufeng Units 3 and 4 is still pending, the construction of Units 1 and 2 received State Council approval in August 2024. As a recent progress, the first safety-related concrete at Lufeng Unit 1 was poured on February 24, 2025, (World Nuclear News, 2025).

Besides all the mentioned reactors in construction, China has more than 60 planned CAP1000 construction projects as well, showcasing their confidence in the technology and its cost. The list includes Haiyang 5 and 6 in Shandong Province, Haixing 1–4 in Hebei Province, Bailong 1–6 in Guangxi

Province, Xianning 1–4 in Hubei Province, Pengze 1–4 in Jiangxi Province, Taohuajiang 1–4 in Hunan Province, Yingtan 1–4 in Jiangxi Province, Nanyang 1–6 in Henan Province, etc. More detailed information can be found at (World Nuclear Association, 2025).

Although the second series of CAP1000s have their fair share of challenges, the cost and schedule reductions estimated for each of these projects are substantial when compared to the first series. Execution of these projects has faced challenges such as delays caused by intricate design refinements, regulatory complexities, and post-COVID global supply chain constraints. However, despite these hurdles, these projects are demonstrating substantial reductions in construction timelines and costs, due to the critical learnings after overcoming the FOAK issues.

Enhancements in modular construction techniques, enhanced project management, and strengthened regulatory oversight are significant advancements that have been developed during the first series deployments and have allowed the ongoing projects to reduce their construction timelines and costs. These advancements have not only improved efficiency and cost management but have also reinforced China's ability to manage large-scale nuclear projects effectively. Additionally, these nuclear initiatives provided positive economic impacts by stimulating local job markets, improving technical capabilities, and growing the national nuclear industry.

3.3.3 Second Series: CAP1400

The Chinese CAP1400 reactor is a promising Gen-III advanced pressurized water reactor design developed by China's State Nuclear Power Technology Corporation in collaboration with Westinghouse Electric Company and based on the AP1000 design. The CAP1400 unit (also referred to as Guohe One) has been constructed at Shidaowan (translated as Shidao Bay).

The CAP1400 generates a power output of approximately 1,400 MWe, compared to the AP1000's 1,117 MWe. CAP1400 was developed by upgrading the power capacity level, optimizing the general parameters, balancing the plant design, redesigning the safety systems and key equipment, and increasing the equipment localization proportion. It also incorporated post-Fukushima safety policies, fulfilled the current safety goals, satisfied the most stringent radwaste discharge standards, and further improved economic competitiveness.

Safety enhancements in the CAP1400 include additional passive safety systems, which rely on natural forces such as gravity and natural circulation, reducing the need for operator intervention and external power sources during emergency situations. CAP1400 has a compact layout, covering an area of only 0.164 m^2/kW. The estimated cost of the first CAP1400 project is about 16,000 CNY/kW ($2,443 USD/kW) (Zheng, et al., 2016). For the NOAK, the cost of CAP1400 is expected to be much lower due to the learning effect, as well as to design completeness, equipment and material localization, improved modular construction design, optimized project management, and economies of scale.

Shidao Bay II Units 1 and 2, located in Rongcheng City Shandong Province, are the first set of CAP1400 constructed, starting in 2019. Unit 1 was connected to the grid on November 4, 2024, while Unit 2 is still under construction. The major issues encountered during the construction of Shidao Bay II Unit 1 were schedule delays during the early stages, primarily due to the 2011 Fukushima accident, FOAK engineering challenges, and supply chain capability and capacity (World Nuclear Industry Status Report, 2020). These delays mirrored similar challenges seen in other Gen-III+ reactor deployments worldwide.

However, positive benefits from learning emerged, including the importance of localized supply chain development and early investment in human capital, which helped reduce dependence on foreign expertise and technology over time (Yicai Global, 2023). Positively, the CAP1400's development bolstered China's nuclear self-reliance and showcased its ability to manage complex nuclear infrastructure projects, enhancing its position in global nuclear technology exports (International Atomic Energy Agency, 2020).

3.3.4 Summary of Design Changes Between Deployments

There are a few notable differences between U.S. AP1000's, Chinese AP1000, CAP1000, and CAP1400 as mentioned here:

- Chinese Design Standards: The CAP1000 is designed to meet local Chinese design standards, such as GB6429 (World Nuclear Association, 2025).
- Localized supply chain: In addition to conforming to local design requirements, the CAP1000 design was improved to minimize supply chain disruptions and reduce tolerance issues in structural module construction that hindered the first series of AP1000s.
- Aircraft impact rule: The U.S. AP1000 design followed changes and guidelines from the NRC to improve the aircraft impact rating of the plant. The first series in China (Sanmen/Haiyang) did not include changes for aircraft impact and kept the original design (Hibbs, 2010) (World Nuclear Association, 2021).
- Reactor Coolant Pumps (RCPs) Frequency: The RCPs in the CAP1000 are redesigned to operate at 50 Hz, aligning with the Chinese power grid frequency, rather than the AP1000's 60 Hz (World Nuclear Association, 2021). This is not expected to make significant construction changes but highlights the changes to integrate with local requirements and simplifying supply chain.
- CAP1400 Design Changes:
  - Larger fuel assembly and steam generators (World Nuclear Association, 2021).
  - SNPTC owns intellectual property rights for anything over 1350MWe, which includes the CAP1400 and potential scale ups. This would include the CAP1700 or CAP2100, which have been proposed but the design completion has not been publicly announced (World Nuclear Association, 2021).

Although there are several differences between the AP1000, CAP1000, and CAP1400 deployments, the changes have been constrained to the specific deployment series and country. For example, none of the Chinese reactors have the same level of aircraft impact rule design changes as the U.S. AP1000's, meaning that within each deployment series, comparisons of cost and schedule (evaluated in section 4) should remain primarily valid and cause only minor deviations.

3.4 Other Proposed/Planned International AP1000 Deployments

According to Westinghouse's website (Westinghouse Electric Company), there are a total of 20 reactors contracted selected for international AP1000 projects in various countries outside of China:

- **Poland**: three AP1000 reactors contracted.
- **Bulgaria**: two AP1000 reactors contracted.
- **Ukraine**: nine AP1000 reactors contracted.
- **India**: six AP1000 reactors selected.

3.5 Summary of Lessons Learned During FOAK Deployments

This section lists some high-impact lessons learned in AP1000 construction projects and the practical challenges that warranted these lessons. The lessons learned documented here summarize the more detailed lessons learned documented in previous literature. Many of the lessons captured in this report can be found in the *DOE Liftoff Report* (Department of Energy, 2024).

- **Lesson 1: Finalize the detailed design before construction.** At both Vogtle Units 3 and 4 and the abandoned V.C. Summer Units 2 and 3, thousands of field change notices and late redesigns were issued after the COL was granted. Each change required reanalysis, rework, and new regulatory reviews, stretching schedules and inflating costs (Department of Energy, 2024).
- **Lesson 2: Conduct a constructability review of the design.** Bechtel's independent audit of V.C. Summer found that "the issued design is often not constructible," recommending an intensified program of constructability reviews to identify drawing holds and design changes well before the work need date (Bechtel, 2016).
- **Lesson 3: Create an integrated project schedule.** Bechtel's forensic review of V.C. Summer (Bechtel, 2016) found that the Integrated Project Schedule carried insufficient detail.
- **Lesson 4: Ensure robust quality assurance from contractors.** The AP1000 relies on large, prefabricated steel concrete modules to shorten onsite construction. In practice, NRC inspectors at the Lake Charles facility found an inadequate Quality Assurance (QA) program, forcing remedial work and reducing the expected schedule advantage (Flitter, 2017).
- **Lesson 5: Conduct project risk assessments.** As evidenced in the twenty-third Vogtle Construction Monitoring (VCM) report (Georgia Power, 2009-2024), Southern Nuclear maintained a risk register during the later stages of construction for capturing threats that had the potential to impact the project and help mitigate the issue if the risk event happened. (Department of Energy, 2024).
- **Lesson 6: Invest early in workforce assessment and training.** Both Vogtle and V.C. Summer suffered acute shortages of qualified craft workers, resulting in productivity losses and schedule slippage. Although not in project management control, COVID-19 also introduced staff and labor shortages, further highlighting the importance of a qualified and available labor force (Department of Energy, 2024).
- **Lesson 7: Structure project finance to absorb FOAK shocks.** V.C. Summer's fixed price EPC contract proved inadequate when costs escalated, leading to abandonment and stranded investments. Vogtle survived only after owners, regulators, and federal backers injected additional guarantees and reallocated risk, demonstrating that robust contingency, risk sharing, and oversight mechanisms are essential until repeat build cost certainty is achieved.
- **Lesson 8: Consolidate EPC authority under a single accountable entity.** Compounding cost overruns at Vogtle contributed to Westinghouse's bankruptcy, which left owners attempting to renegotiate scope and financing (Patel, 2017). At V.C. Summer, Bechtel's independent audit highlighted fragmented responsibilities, unclear decision pathways, and low workforce morale, also resulting in cost and schedule overruns.
- **Lesson 9: Align licensing strategy with design maturity to avoid costly regulatory churn.** The U.S. NRC Part 52 approach was intended to lock the design, yet dozens of departures from the certified AP1000 baseline (and consequent LARs) still occurred after COL issuance. Completing the design, including constructability reviews, before submitting the license application would minimize the amount of regulatory burden during construction.

3.6 Summary of Lessons Applied During Chinese Second Series of Deployments

The success of the Chinese deployments not only stems from several key advantages but also their effectiveness of transferring learnings within the nuclear industry and their strategic perseverance to deploy a large fleet of nuclear reactors. There are some advantages that are difficult to duplicate outside of China, such as low labor costs; however, some of the easier to transfer learnings that can be seen as key are:

- **Centralized transfer of lessons learned.** China benefits from a nationalized nuclear industry that effectively transfers lessons learned from the AP1000 projects across various initiatives. This required time, labor, and investment for transferring the lessons to the rest of their nuclear industry and the efforts culminated in the improved CAP1000 design, which now has been chosen for several projects across the country. Additionally, the development of the CAP1400 had also incorporated these lessons learned and resulted in a shorter construction time.
- **Localization and standardization.** The CAP1000 derivative increased Chinese content to more than 80% and simplified civil works to local codes. These changes aim to push overnight construction costs toward the levels achieved for the indigenous CPR 1000 series, while also reducing long lead imports.
- **Committed orderbook and successive deployments.** China's nuclear industry has had broad and consistent support, allowing for long-term planning without significant uncertainty and resulting in committed and successive deployments. This enables deployments to come down the learning curve, reducing cost and schedule. Additionally, their nuclear industry maintains consistency, which enables a growing experience pool of knowledge that can be transferred between projects.

4. EVALUATION OF DURATIONS, SCHEDULES, AND COST

The analytical evaluation of timelines and expenditures is crucial for understanding the lessons learned from past AP1000 construction projects and applying them to future builds. This section delves into the detailed timelines and expenditures associated with the AP1000 projects, focusing on how delays, cost overruns, and other challenges were managed in subsequent builds. By analyzing digitized schedules and comparing them across different projects, the aim is to identify patterns and potential areas for improvement. The evaluation is based on the milestone data from Vogtle Units 3 and 4, V.C. Summer 2 and 3, as well as international projects such as those in China, to provide a comprehensive understanding of the factors influencing construction timelines and costs.

4.1 Schedule Analysis for Recent and Ongoing AP1000 Deployments

Across the projects examined, there is a clear trend of improving construction duration from FOAK to subsequent builds. Table 3 summarizes the planned vs. actual construction timelines for key projects.

Table 3. Planned vs. actual construction duration (first nuclear concrete to commercial operation).

Project (Reactor Units)	Reactor Type	Start of Construction	Planned Operation	Actual Operation	Actual Duration vs. Plan
Vogtle 3 & 4 (2×AP1000)	FOAK AP1000	2013 (Mar & Nov)	2016–2017 (target)	2023 (Jul) and 2024 (Apr)	~10–11 years vs. 4 years planned
Sanmen 1 (AP1000)	FOAK AP1000	Apr 2009	~2014 (initial)	Sept 2018	~9.4 years vs. ~4.5 years planned

Project (Reactor Units)	Reactor Type	Start of Construction	Planned Operation	Actual Operation	Actual Duration vs. Plan
Sanmen 2 (AP1000)	FOAK AP1000	Dec 2009	~2015 (initial)	Nov 2018	~8.9 years vs. ~4.5 years planned
Haiyang 1 (AP1000)	FOAK AP1000	Sep 2009	~2014–2015	Oct 2018	~9.1 years vs. ~5 years planned
Haiyang 2 (AP1000)	FOAK AP1000	Jun 2010	~2015–2016	Jan 2019	~8.6 years vs. ~5 years planned
Shidao Bay II Unit 1 *(CAP1400)*	FOAK CAP1400	Jun 2019	Feb 2024 (56-month plan)	Oct 2024 (grid connect)	~5.3 years vs. 4.7 years planned
Lianjiang 1 (CAP1000)	NOAK AP1000	Sep 2023	2028 (scheduled)	*2028 (expected)*	*(In progress, target ~4.7 years)*
Sanmen 3 & 4 (CAP1000)	NOAK AP1000	Jun 2022–March 2023	2027–2028 (scheduled)	*2027–2028 (expected)*	*(In progress, target ~4.7 years)*
Haiyang 3 & 4 (CAP1000)	NOAK AP1000	July 2022–April 2023	2027–2028 (scheduled)	*2027–2028 (expected)*	*(In progress, target ~4.7 years)*

The table above provides the following key takeaways:

- **FOAK AP1000s:** Vogtle, Sanmen, and Haiyang had actual build times roughly double the planned durations. Vogtle in the United States was an outlier with ~10+ years (from first nuclear concrete). Chinese FOAK builds took ~8–9 years, still about 4 years longer than initially projected.
- **Learning is evident:** Later units in the initial batch (i.e., Haiyang-2) slightly outperformed earlier ones (i.e., Sanmen-1) in schedule, and by the time of CAP1400, China effectively met its ~5 year target (5.3 years actual to grid).
- **Future builds:** The second series of CAP1000s are estimated for ~4.5–5 year timelines, which if realized by Lianjiang and others, confirm a 50% reduction in construction time compared to FOAK AP1000 projects. This is a huge improvement, directly reducing the schedule risk and interest costs.

4.1.1 AP1000 Milestone Tracking

Many milestones are commonly used for project progress tracking and are often publicly released in news articles. This analysis focuses on a granular view of the construction timeline, evaluating the project timeline with a view of the major milestones and module placement dates from the first nuclear concrete. Figure 7 shows a graphic representation of the timeline. The list of milestones is non-comprehensive but represents large modules and significant events that are important for tracking AP1000 construction. These milestones will be used in the following sections for a quantitative comparison between projects. The milestone descriptions, in order, are:

- **First nuclear concrete:** after site prep and excavation, this marks the official start of construction
- **CA20 module placement:** auxiliary building module
- **CA01 module placement:** steam generator and refueling canal inside containment wall module
- **CA03 module placement:** in-containment refueling water storage tank
- **Reactor vessel installation:** internal structure where nuclear reaction occurs

- **Containment vessel top head:** large "lid" type structure placed on top of containment
- **CB20 module placement:** containment water tank located above containment for passive cooling
- **Cold hydro:** ensures successful construction of pressurized piping and equipment
- **First criticality:** initial startup of reactor and first self-sustaining nuclear reaction
- **Grid connection:** integration of the nuclear power plant with the electrical grid
- **Commercial operation:** this marks the end of construction and successful completion of project.

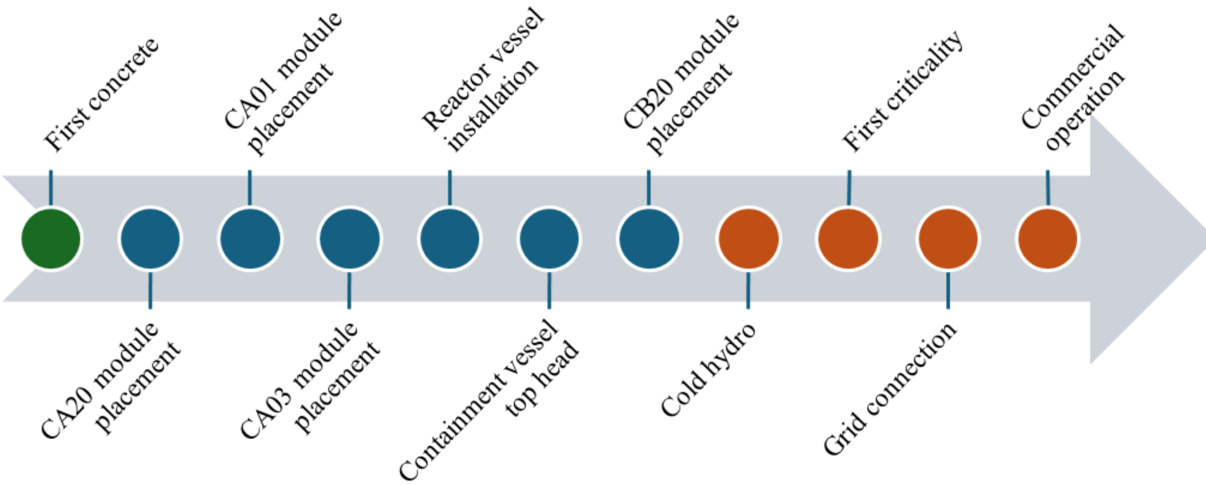

Figure 7. The timeline of tracked AP1000 milestones used in this analysis.

4.1.2 Vogtle and V.C. Summer Construction Timelines

The analysis started by gathering milestone completion data for Vogtle Units 3 and 4 and V.C. Summer from various news sources and reports, such as the VCM reports (Georgia Power, 2009-2024). Additionally, the submission dates from a total of 187 LARs were gathered, ranging from 2012 to 2022. This data was then plotted to visualize the timelines and LARs, as shown in Figure 8. The 187 LARs are plotted with blue dots, and the milestones are tracked using color bars.

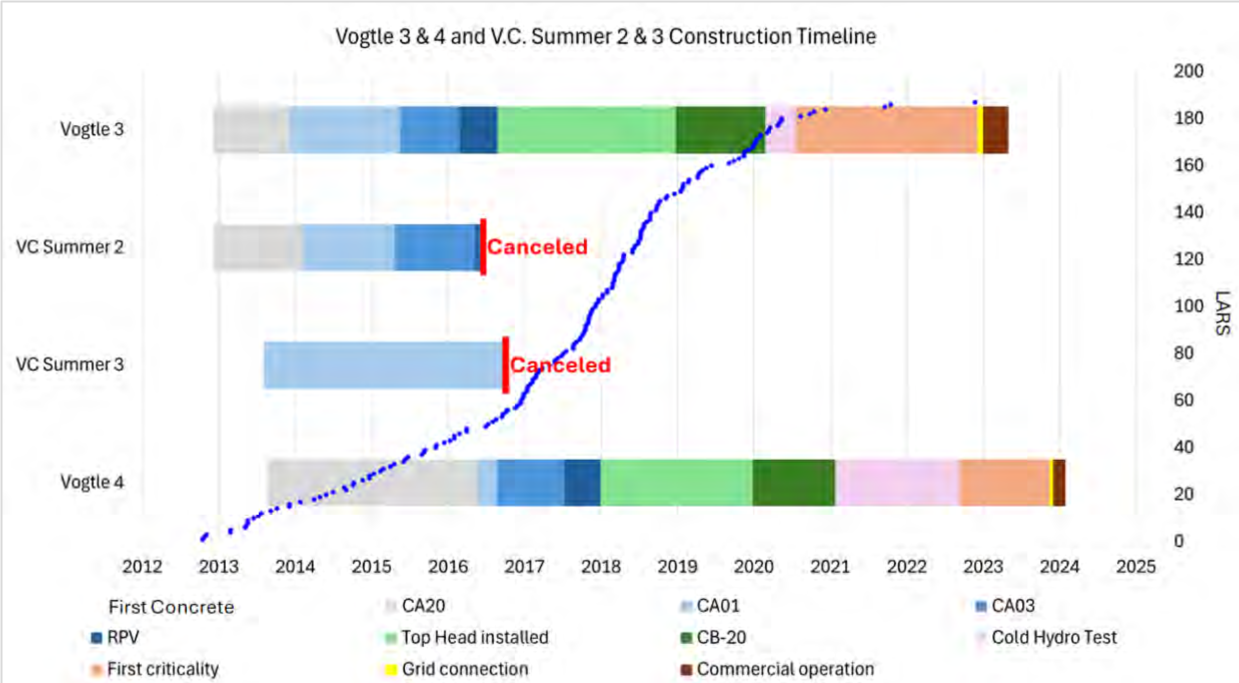

Figure 8. Vogtle 3 and 4 and V.C. Summer 2 and 3 milestone duration schedules with LARs overlapped. Note: V.C. Summer Unit 2 was terminated during the reactor pressure vessel (RPV) installation process, and V.C. Summer Unit 3 terminated during CA01 installation process. The duration of CA20 is unknown for V.C. Summer Unit 3.

The graph indicates that the LARs spanned almost the entire construction period of Vogtle, demonstrating that the many design changes and significant rework contributed to delays in the construction process. Although it is expected to see learning or changes in the schedule from Unit 3 to Unit 4, this does not show up in the milestone data due to the interconnectedness of the projects. For example, the same workforce performing installations on Unit 3 would also be required for Unit 4, resulting in Unit 4 milestone duration from first nuclear concrete being almost always about a year later than those of Unit 3 to account for the sharing of resources. There are, however, some noticeable differences in the durations between milestones. Attempting to identify and quantify the differences between Unit 3 and Unit 4 better, the durations for each milestone in Vogtle Units 3 and 4 were compared and plotted in Figure 9.

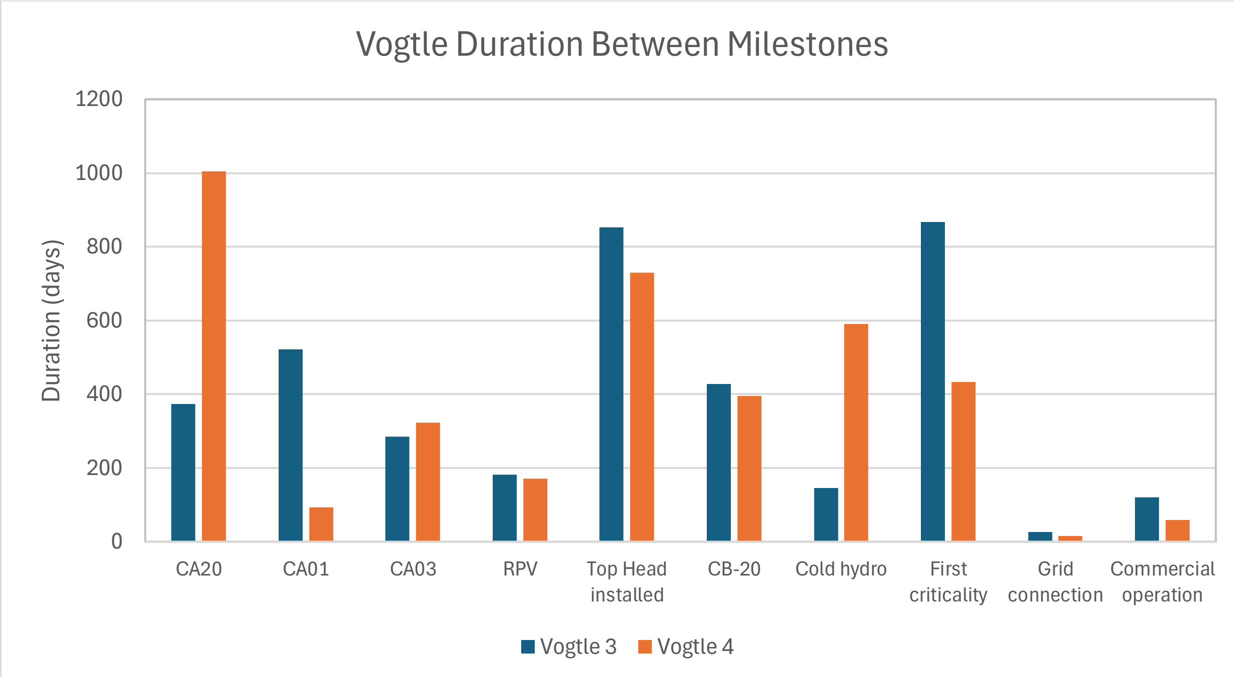

Figure 9. Durations between milestones in Vogtle 3 and Vogtle 4.

In this figure, although the durations differ in length, the data does not show a consistent trend or reduction from Vogtle Unit 3 to Vogtle Unit 4. Since this milestone data is only based on the dates when the specific milestones were reached and not on the amount of labor and time spent on each task, it provides only a partial observability into the project. It is therefore inconclusive for analyzing cost and schedule reductions. As noted previously, the Vogtle Units 3 and 4 projects were significantly intertwined, sharing resources throughout the construction project. For example, the same labor force was used for both projects; therefore, any rework-based delays in Vogtle 3 would have caused delays to Vogtle 4. Accurately quantifying any cost or schedule reductions between the two projects would require more data than is publicly available, such as labor expenditures for each task. This data does not indicate any differences in labor or costs involved in achieving each milestone, which are ultimately true indicators of learning.

Although the publicly available milestone dates are inconclusive on schedule reductions, the *DOE Liftoff Report* quotes that Unit 4 was ~20% cheaper than Unit 3 (Department of Energy, 2024). The report also mentions that key testing milestones were completed ~38–76% faster, and engineering service requests dropped ~50%. These reductions are significant indications that there was learning between Units 3 and 4, and that AP1000 construction is moving down the cost curve.

4.1.3 Chinese AP1000 Construction Timelines

As indicated in Section 3, there is significant experience and progress with construction in China surrounding the AP1000 and the local variant, the CAP1000. With several complete reactors and more under construction, China serves as a referenceable case study for the analysis of learning from fleet deployments. Figure 10 illustrates the timelines of critical durations between milestones for the Chinese builds, along with the Vogtle 3 and 4 plants. Data sources used for Figure 10 include IAEA Power Reactor Information System (PRIS) (International Atomic Energy Agency, 2025), World Nuclear Association web page (World Nuclear Association, 2025), China Nuclear Power Information Network web page (China Nuclear Power Information Network, 2025), etc.

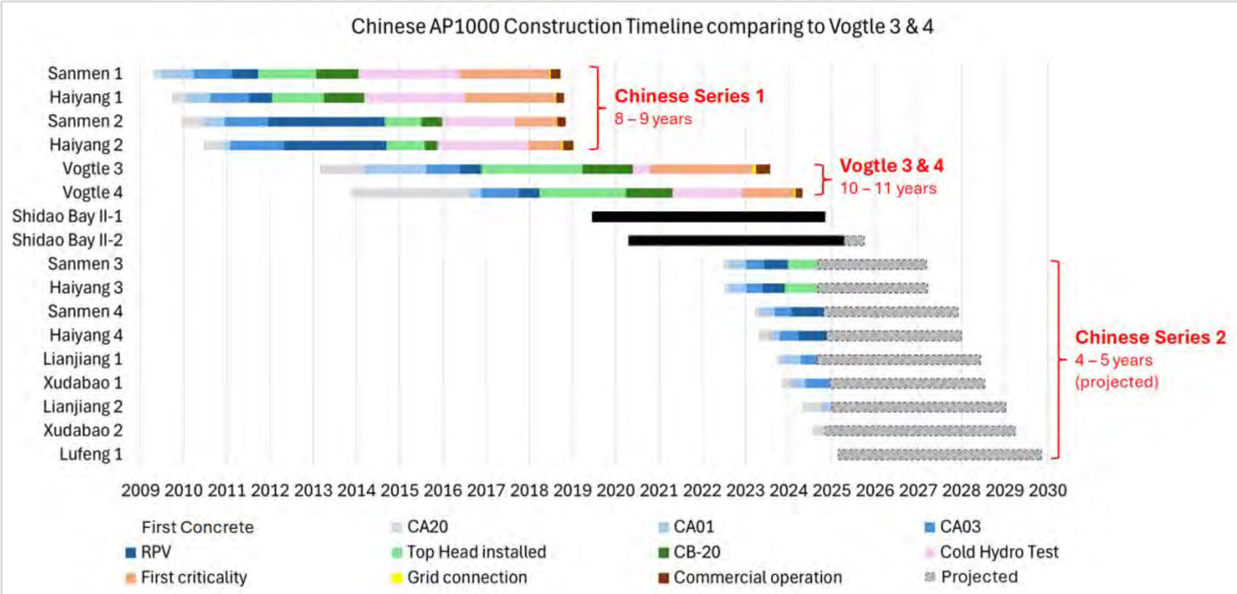

Figure 10. Chinese AP1000/CAP1000 and CAP1400 construction milestones, with the construction timelines of Vogtle Units 3 and 4.

From Figure 10, the first series of Chinese builds, which include Sanmen 1 and 2 and Haiyang 1 and 2, commenced in 2009 and were completed within a span of 9 years—not significantly different from the U.S. experience. However, significant timeline reductions can already be seen in successive builds. The second series of CAP1000 constructions, comprising Sanmen 3 and 4, Haiyang 3 and 4, Lianjiang 1 and 2, Xudabao 1 and 2, and Lufeng 1, began in 2022–2025 and are currently ongoing. Based on the information presented in Table 3, the projected completion for the ongoing units is estimated and plotted in a dashed pattern. Figure 10 also includes the two Chinese CAP1400 units at Shidao Bay; its Unit 1 has completed construction and was connected to the grid on November 4, 2024, while the construction of Unit 2 is ongoing. The timelines for Shidao Bay are solid black lines due to the limited availability of data.

A noteworthy reduction in schedule durations can already be observed when comparing early-stage milestones, such as CA20, CA01, and CA03, between the first and second series of Chinese CAP1000 builds. While not a perfect comparison, Shidao Bay Unit 1 (CAP1400) has already been completed and in commercial operation for ~5.3 years, a significant reduction from the ~9-year durations experienced during the first series of AP1000s. This suggests improvements in construction processes and efficiency in the later projects.

4.1.4 Quantifying Schedule Reductions During Chinese AP1000 Deployments

The timelines of AP1000, CAP1000, and CAP1400 reactors in China have provided valuable evidence into the learning and efficiency gains that can be achieved through successive builds. There is an opportunity to quantify this learning to help estimate potential gains for future builds.

There is a noticeable difference in the schedule between the first series (Sanmen/Haiyang) and second series deployments. Learning is often thought of at a plant-to-plant or even unit-to-unit level, however in China, the learning is far more evident after the first series of FOAK reactors were completed. The interconnectedness and the overarching problems that affected the entire first series diminished many of the learnings from a unit-to-unit perspective. Therefore, for further analysis, the series were grouped according to series number to better understand the learnings once the design was finalized and FOAK issues were resolved. To better visualize these differences, the milestone completion days (from first nuclear concrete) are illustrated in Figure 11.

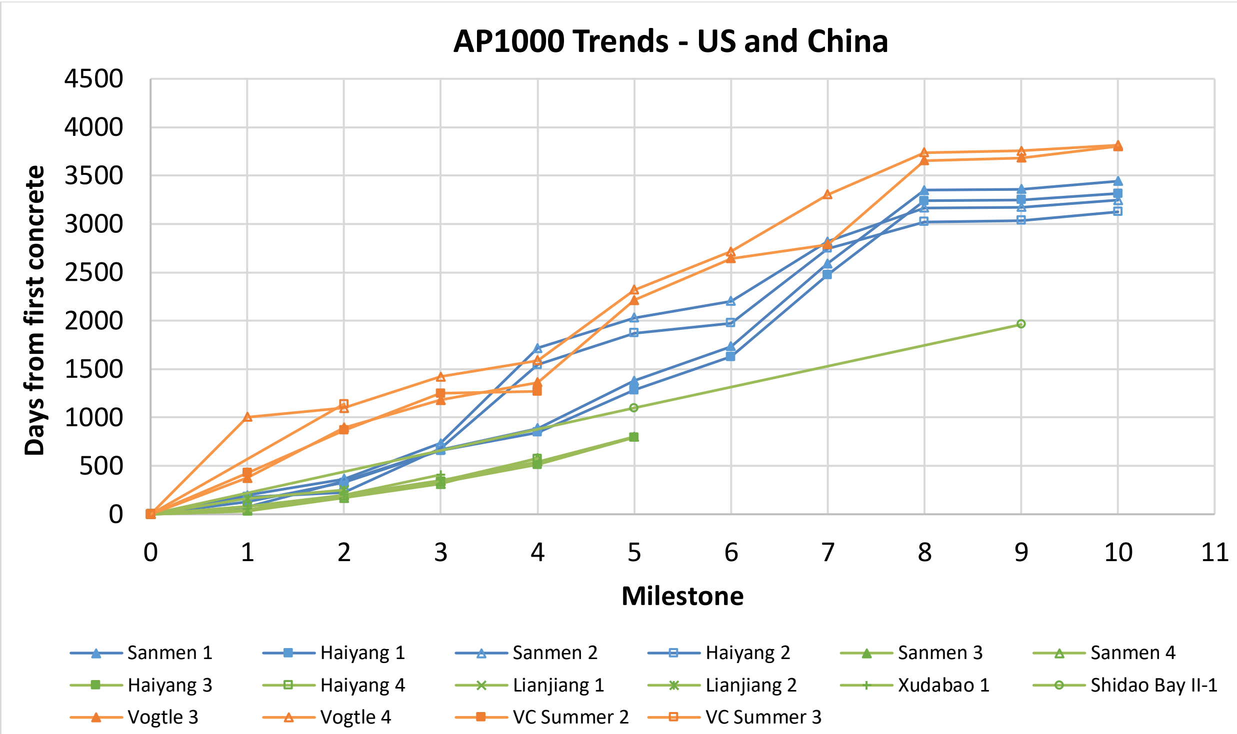

Figure 11. Milestone completion day, measured from first nuclear concrete.

Figure 11 plots the milestone completion days for each set of projects: U.S. plants (orange), China's first series (blue), and China's second series (green). This includes AP1000, CAP1000, and Shidao Bay II-1, which is a CAP1400. The x-axis represents the milestone number, and the y-axis represents the days from first nuclear concrete when each milestone was completed.

From the figure, there is a similarity in FOAK construction durations between the United States and Chinese first series, and then a reduction in construction time for the second series of Chinese projects. While the China first series and second series started on similar trajectories, it is clear that issues began to delay milestone progress in the first series around the fourth milestone. These issues, similar to the U.S. experience as discussed in Section 3, caused significant challenges for construction, resulting in rework and redesign, and ultimately the schedule slippage that is noticeable in the plot.

For the second series, there are significant reductions that can be seen in the early stages of construction when compared to the first series. A significant marker of these reductions can be seen exemplified by Shidao Bay II-1, having completed grid connection (milestone 8 on the plot) in 1,961 days, approximately a 39% reduction than the average of the Chinese first series (i.e., 3,205 days). To illustrate these trends further, Figure 12 provides a linear fit for the same data as shown in Figure 11.

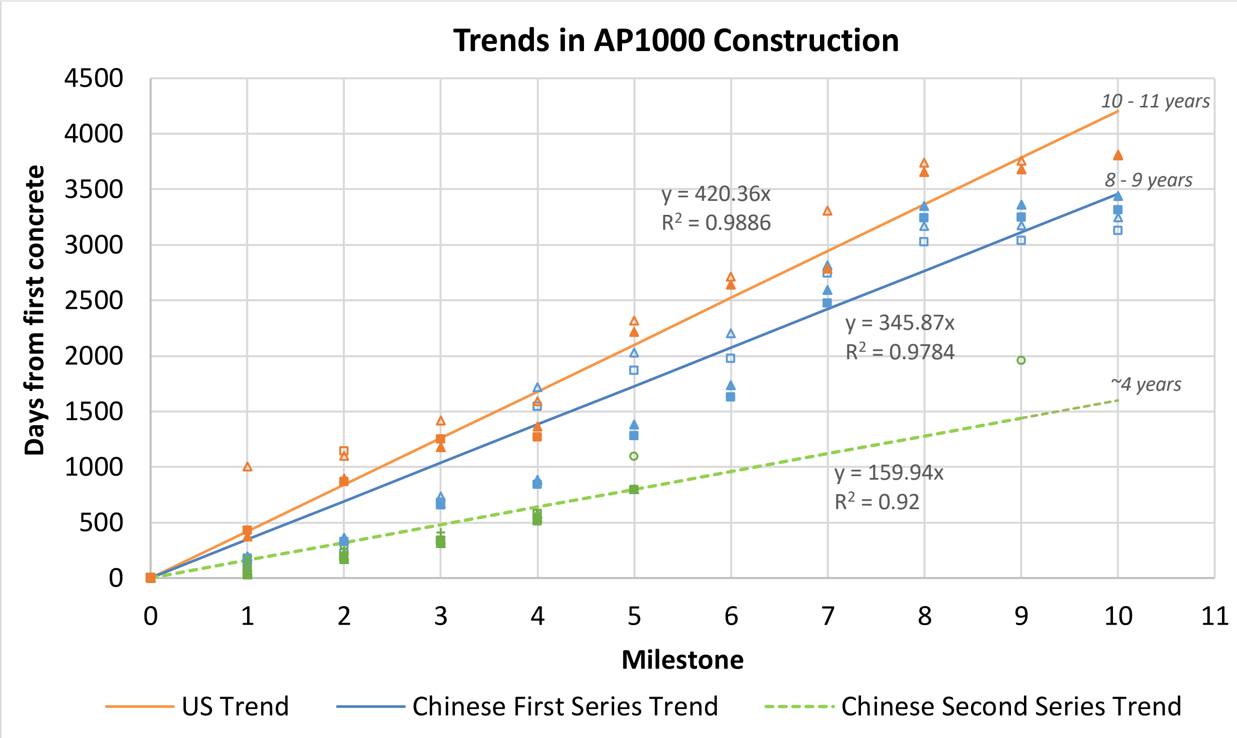

Figure 12. Linear trends between U.S. and both series of Chinese AP1000 construction.

The linear fit shows significant reduction in construction durations for the second series of Chinese projects. Looking at the results, the linear fit suggests a significant reduction from the first series to the second series.

It is important to note that this is only for an illustrative comparison, as a linear trend fit to milestones represented as integers may not be the most accurate method and assumes that each milestone is the same length. For example, many late-stage milestones have varying lengths, some longer and some shorter. These differences are not captured well with a linear model. Additionally, the second series of Chinese builds is represented primarily by the earlier milestones, which tend to be shorter. However, regardless of modeling assumptions, the linear trends fit decently well to the data and are showing significant schedule reductions between the first and second series in Chinese deployments. Nonetheless, this is a good indicator of progress.

To further quantify the series-to-series implications of a reduced schedule, the average durations from first nuclear concrete for each milestone were evaluated, highlighting the improvements achieved in the second series of projects (see Figure 13).

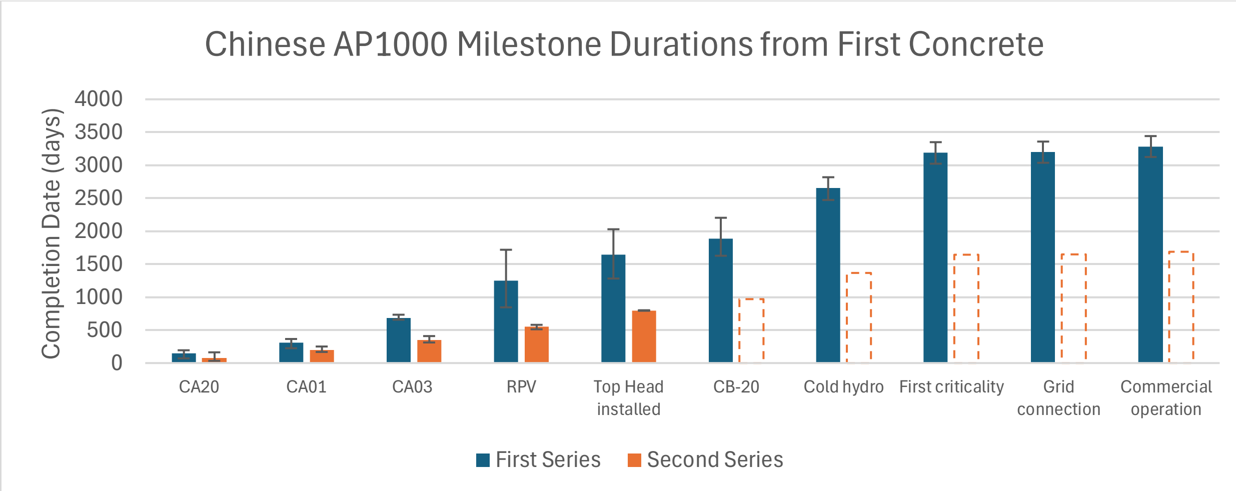

Figure 13. Average duration from first nuclear concrete for each milestone for Chinese projects. Dotted lines represent projected duration from first nuclear concrete.

The blue bars represent the average completion data for the Chinese first series and orange bars represent the average completion data for the Chinese second series. Due to the second series being so relatively recent, there are several milestones that are yet to be reached by any second series project. These are represented by dotted lines where the height is based on the second series average reduction percentage, emphasizing the accelerated timelines and showcasing early completion times in comparison with the first series. The error bars represent the maximum and minimum values for the dataset, showing the full range of the data.

There are two key takeaways from duration from first nuclear concrete data contained in this plot:

1. average duration from first nuclear concrete is reduced by ~48%, and
2. variance of average duration from first nuclear concrete (spread in data) is reduced by ~60%.

The average duration from first nuclear concrete was calculated by measuring the difference between each milestone duration from first nuclear concrete from the Chinese second series to the average duration from first nuclear concrete of the Chinese first series milestones. The variance reduction was calculated using the geometric mean of the coefficient of the variation calculated for each milestone. A summary of the duration from first nuclear concrete data can be seen below in Table 4.

Table 4. Average reduction for Chinese milestone duration from first nuclear concrete.

Duration from first nuclear concrete					
	CA20	CA01	CA03	RPV	Top Head
First series	143	314	684	1249	1641
Second series	74	197	346	547	797
Reduction	-48%	-37%	-50%	-56%	-51%

4.1.5 Reductions in Durations Between Milestones Observed During Chinese AP1000 Deployments

To better understand the learning effects, durations between milestones (i.e., the time it takes to finish a milestone, as measured from the end date of the previous milestone) were calculated and the reductions quantified. This gives a more detailed understanding as to which milestones are experiencing better schedule reductions. The results of this analysis can be seen in Figure 14.

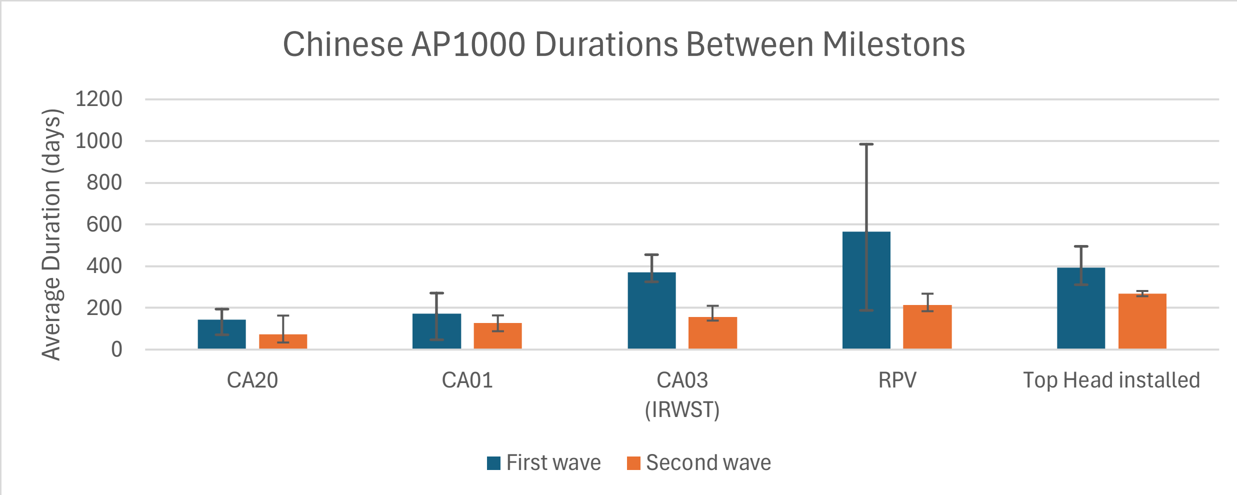

Figure 14. Average duration between milestones during Chinese AP1000 builds.

Figure 14 illustrates the average milestone duration for the first series (blue) and second series (orange) of Chinese AP1000 deployments. The error bars represent the minimum and maximum values contained in the data. Several milestones are omitted from this plot because the second series projects have not completed those milestones. As shown in the figure, the milestone duration and variance have both dropped significantly from the first to second series.

There are two key takeaways from milestone duration data contained in this plot:

1. Average milestone duration is reduced by ~42%
2. Variance of the average milestone duration (spread in data) is reduced by ~46%.

The average milestone duration was calculated by comparing the duration of each milestone in the second series to the average duration of milestones in the first series. The variance reduction was calculated using the geometric mean of the coefficient of the variation calculated for each milestone. A summary of the milestone duration data can be seen below in Table 5.

Table 5. Average reduction for Chinese AP1000 durations between milestones.

Duration Between Milestones (days)					
	CA20	CA01	CA03	RPV	Top Head
First series	143	172	370	564	392
Second series	74	128	157	214	269
Reduction	-48%	-26%	-57%	-62%	-32%

A common topic for discussion regarding expanded deployment is the potential learning achieved between each successive unit or plant. To evaluate this, durations between milestones were normalized with Sanmen 1 (first reactor to pour concrete and reach commercial operation) and analyzed to evaluate the change. These results of this analysis can be seen, plotted in Figure 15.

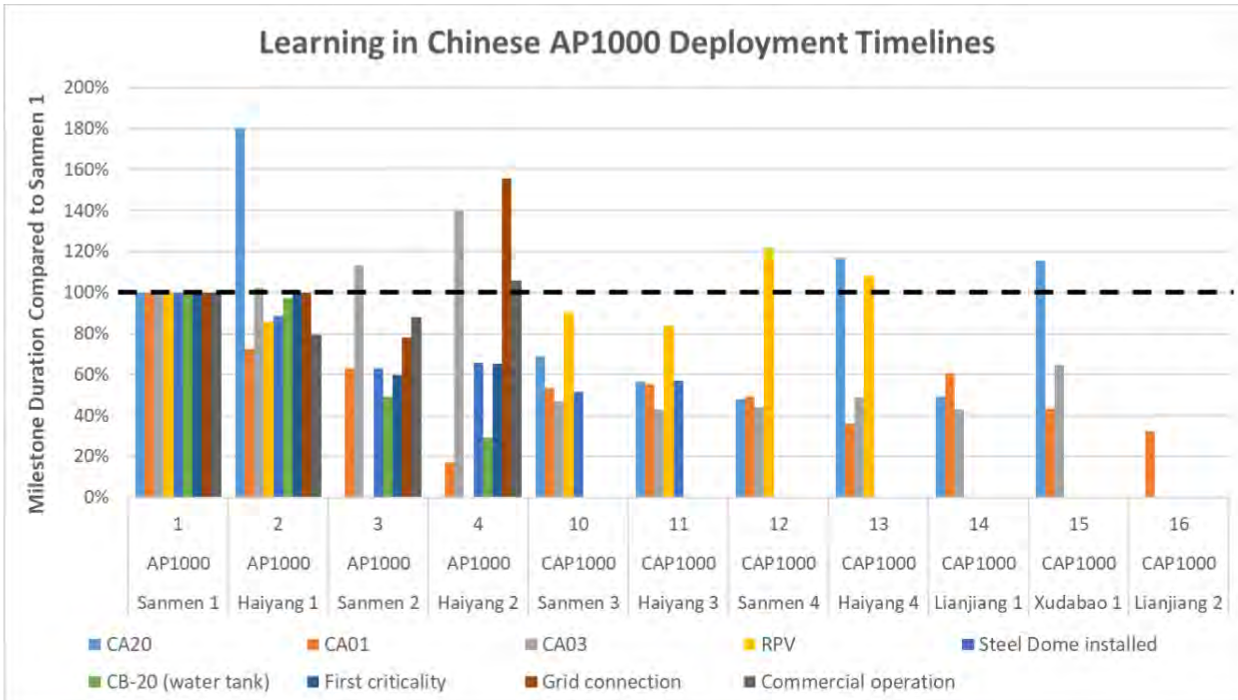

Figure 15. Inter-milestone durations for each reactor, normalized to Sanmen 1 (outliers removed).

The data shows a slight trend of reduced duration between milestones in the second series of Chinese AP1000 builds. For visualization purposes, outliers were removed as they were visually difficult to fit onto the plot. The problems associated with these outliers can often be attributed to other factors not directly related to the milestone itself.

4.2 Capital Expenditures Evaluation for AP1000 Deployments

Cost outcomes between the U.S. and Chinese projects vary drastically. Table 6 compares the capital cost figures (in reported dollar-year) for the case studies, highlighting FOAK overruns. V.C. Summer is omitted from this table, having been canceled before a final cost could be accurately estimated.

Table 6. Capital expenditures comparison.

Project (Reactor Units)	Original CapEx Estimate	Final/Latest CapEx Estimate	Cost Overrun (%)	Cost per kWe (overnight)
Vogtle 3 & 4 (AP1000)	~$14B (Mixed USD)	~$35B (Mixed USD)	~150% (Mixed USD) ~128% (adjusted for inflation)[1]	~$11,000/kW (Mixed USD)
Sanmen 1 & 2 (AP1000)	CNY 32.4B (~$5.0B USD-2008)	CNY 50B (~$7.3B USD-2018)	~54% (not adjusted for inflation)	~$2,440/kW (2018 USD)
Haiyang 1 & 2 (AP1000)	Not publicly reported	Not publicly reported	N/A (project ongoing)	N/A (project ongoing)

Project (Reactor Units)	Original CapEx Estimate	Final/Latest CapEx Estimate	Cost Overrun (%)	Cost per kWe (overnight)
Shidao Bay II – Unit 1 & 2 *(CAP1400)*	CNY 44.8B (~$6.84B USD-2016)	Not publicly reported	Not publicly reported	~$3,100/kW[3] (2016 USD)
Lianjiang 1 & 2 (CAP1000)	$5.6 billion USD-2022 (est.)	Not publicly reported	N/A (project ongoing)	N/A (project ongoing)
Sanmen 3 & 4 (CAP1000)	Not publicly reported	Not publicly reported	N/A (project ongoing)	N/A (project ongoing)
Haiyang 3 & 4 (CAP1000)	Not publicly reported	Not publicly reported	N/A (project ongoing)	N/A (project ongoing)

Table Sources:
Vogtle: (Shirvan, 2024); Sanmen: (World Nuclear Association, 2025); Lianjiang: (Dalton, 2023); Shidao Bay: (Zheng, et al., 2016)
[1]Costs escalated for inflation to 2024 USD using the assumed yearly expenditure rate and interest rate on debt of 5%.
[2]Limited public data available. Assumed similar to Sanmen 1 & 2.
[3]Assumes similar overnight ratio as Sanmen and Haiyang

Several of the milestone fields in this table are yet to occur at the time of this publication, and other relevant data are not publicly reported. However, the reactors with available data or estimates show learning from the first series.

Some key takeaways from the table:

- As noted in the *DOE Liftoff Report*, "cost overruns are not unique to the nuclear industry and are a feature of most megaprojects" (Department of Energy, 2024). This is evident across all FOAK AP1000 projects, including China, highlighting the difficulties in megaprojects and especially FOAK nuclear projects that can easily compound cost overruns.
- Vogtle's cost overrun stands out with having significantly high overruns. However, the unit cost of $11,000/kWe is not representative of what an AP1000 "should" cost going forward, as many of the costs are nonrecurring as FOAK issues are expected to be addressed (Shirvan, 2024) (Department of Energy, 2024).
- Chinese AP1000 costs were an order of magnitude lower than Vogtle in absolute terms. Sanmen's two units came in around $6–7.5B total—that is roughly $3 billion per reactor. The reported unit cost of ~$2,400/kW for Sanmen is close to what one would expect for an NOAK plant. This underscores that the AP1000 design itself is capable of being built economically in the right context.
- The CAP1000 projected costs of $5.6B for two units (Lianjiang) confirm the achievement of low costs through replication and learning.

4.3 Discussion of AP1000 Construction Evaluations

The evaluation of AP1000 construction projects reveals significant cost and schedule reductions, particularly from the first to second series of Chinese deployments. The comparison of milestone data between Vogtle Units 3 and 4 and various international projects highlights improvements in construction timelines and costs. Learning is evident in Chinese deployments and between Vogtle 3 and 4, as reported in the *DOE Liftoff Report* (Department of Energy, 2024). Chinese second-series deployments have achieved approximately a 48% reduction in average milestone duration from first nuclear concrete and a 42% reduction in average durations between milestones compared to the first series, with a notable reduction in variance as well. The reduction from the Chinese first series AP1000s to the ongoing second series of CAP1000s highlights the importance of transferring lessons learned to enable these reductions. Many design changes, fabrication practices, and improvements (such as those discussed in Section 3.3.4) have likely contributed to the reductions seen from series to series. Furthermore, significant time and investment were likely required to achieve such substantial reductions through the application of lessons learned, something that could be expected across all reactor types and future deployments.

Note that neither the U.S. nor Chinese data contain detailed labor or cost estimates, which could change the schedule reduction quantifications. However, these findings emphasize the positive impact that repeated deployments, experience, and application of lessons learned can have for new nuclear reactor deployments.

5. POTENTIAL AP1000 COST[b] AND SCHEDULE REDUCTIONS WITH REPEATED BUILDS

Analysis of the Chinese AP1000 construction timelines presented in the previous section showed significant schedule reductions from the first series to the second series of AP1000/CAP1000 deployments. The construction timelines for Chinese projects have experienced reductions of 40–50%, and although there is not enough data to quantify the reduction in cost, the OCC might also decrease by a similarly significant amount. In the United States, the *DOE Liftoff Report* (Department of Energy, 2024) noted that Vogtle Unit 4 was about 15–20% less expensive than Unit 3. Given the data collected and analyzed in this report, there is very strong reason to believe that the next AP1000 projects in the United States can see significant reductions in cost and schedule if deliberate efforts are made to mitigate previously identified FOAK challenges. Shirvan (2024) estimated the cost of the next greenfield AP1000 plant in the United States to be \$9,300/kWe to \$11,600/kWe (33 to 38% reduction) and the construction duration to be 80 to 96 months (25 to 35% reduction).

The goal of this section is to further analyze the reduction in AP1000 cost and schedule in the United States from the first series (Vogtle 3 and 4) to the second, third, and subsequent series. Typically, cost reductions through repeated deployments are characterized by learning rates and NOAK costs. However, the term NOAK can be abstract and is interpreted as *sometime in the far future* and, therefore, is often unnoticed. To delve deeper into FOAK-to-NOAK reductions and breakdown the cost (and its reduction) of each plant with repeated deployments, a cost reduction framework was developed by (Bolisetti, et al., 2024). This framework inputs the Well-Executed (WE)-FOAK and NOAK cost estimates for a certain plant. WE-FOAK represents the FOAK cost in a scenario where the project is executed perfectly and there are no overruns. This is an idealized scenario that has almost zero project uncertainties and all the levers in the cost reduction framework (e.g., design completion before construction, EPC proficiency) are perfect. The WE-FOAK cost represents a highly optimistic cost estimate of the project before it begins.

The model uses a set of "levers" that represent the user's understanding of high-level project and decision-making parameters (e.g., design completion before construction, EPC proficiency). Using dozens of heuristics or "back-of-the-envelope" calculations, the framework projects the cost of FOAK, which would be the WE-FOAK cost plus overruns, 2OAK, 3OAK, and so on. In addition to modeling the

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[b] For consistency, all costs reported in this section are in 2024 USD, unless stated otherwise.

overruns in the FOAK plant, the framework also models reduction in overruns as more plants are built, as well as reduction in cost due to learning from experience.

In this section, this framework is applied for the next AP1000 plants in the United States, using Vogtle Units 3 and 4 together as the FOAK case. It should also be noted that in this report, a series-to-series cost reduction is modeled instead of a unit-to-unit cost reduction, like the analysis in Section 3. For example, Units 3 and 4 in Vogtle are lumped into one series, and the next series would be another two-unit AP1000 plant. This is because of the significant interdependencies between the workforce, supply chain, and project management of various plants and units built around the same time, which are very difficult to disentangle without access to detailed cost, schedule, and labor data from individual units. The AP1000 cost reduction modeling was done in the following steps:

1. *Estimate the WE-FOAK and NOAK costs for the AP1000 plant*: The WE-FOAK and NOAK costs and schedules for the AP1000 were taken from (Stewart & Shirvan, 2022) and (Stewart & Shirvan, 2023), who estimate the cost of a large passively safe reactor that is very similar to the AP1000. The WE-FOAK cost and schedule (including startup) were estimated to be around $7000/kWe and 96 months and $4,700/kWe and 50 months for NOAK in 2024 USD. The historical average OCC of the U.S. PWRs based on the better experience construction projects is $5,830/kWe in 2024 USD (Ganda et al., 2017).
2. *Calculate the externality adjusted FOAK cost of Vogtle Units 3 and 4*: The combined OCC of Vogtle Units 3 and 4 is $15,000/kWe in 2024 USD (Shirvan, 2024). However, the construction of these plants was interrupted by the bankruptcy of Westinghouse and the COVID-19 pandemic, both of which are very unlikely to happen again for the build of the next AP1000 plants in the United States. To remove these externalities from the FOAK costs for modeling purposes, a literature search was performed to quantify the cost and schedule impact of these events on the Vogtle project. Table 7 summarizes these impacts and presents the externality adjusted FOAK cost and schedule from Vogtle Units 3 and 4. As shown in the table, these externalities caused a delay of 13–16 months and a cost increase of about $600/kWe.
3. *“Calibrate” the cost reduction tool so that it projects the FOAK*: To use the cost reduction framework for the next AP1000 plants, the underlying correlations were calibrated such that the FOAK cost and schedule from the framework were close to those calculated in Table 7. While performing this calibration, a representative set of levers were chosen for the Vogtle project and the readiness of the U.S. nuclear industry for nuclear construction.

Table 7. Vogtle 3 and 4 costs and duration calculation for use in cost reduction model. The cost reduction model is not made to handle significant deviations from black swan events. Therefore, the OCC and duration targets were updated to not include COVID-19 or the WEC bankruptcy.

	OCC ($/kWe)	Duration (Months)	Notes and Sources
Realized Values 2024	$15,000	130	(Shirvan, 2024)
Bankruptcy Delay	$500	10	(Shirvan, 2024)
COVID-19 Delays	$73	3 - 6	Georgia's first delay announcement for 3 months after COVID in October 2021 (PR Newswire, 2021) In Feb 2022, Georgia Power announcement additional 3–6 month delays (Williams, 2022)

			$160M in schedule impacts (Georgia Power Company, 2023)
COVID-19 Costs	$18	N/A	$40M in direct costs (Georgia Power Company, 2023)
Resulting Total	$14,409	114 - 117	

The calibrated framework was then used to project the OCC and construction duration for a total of 10 AP1000 builds (each series being a two-unit plant) for two scenarios. This included a moderate scenario, which represents a realistic execution of the next AP1000s that will likely be built with a smaller cost than Vogtle Units 3 and 4, but still higher than the WE-FOAK cost. This is also referred to in the text as “representative of United States experience” because the tool uses correlations tied to the cost reductions are based off the past U.S. nuclear industry experience. Modeling this scenario included using default values for the levers that determine the rates of EPC proficiency increase and learning as assumed in the cost reduction framework (Bolisetti, et al., 2024). That is to say that this scenario models a realistic pathway to cost reduction that is consistent with historical data. This scenario also assumes that each subsequent build happens on a greenfield site, and therefore, there is a minor loss in learning and standardization.

The second is a highly optimistic scenario, where the next AP1000 builds in the United States follow a similar schedule reduction that is seen in China. This is also referred to in the text as “representative of the Chinese Experience.” Unlike the U.S. nuclear industry, the Chinese nuclear industry has been actively building and exercising their workforce and supply chain for decades. Accordingly, this scenario was modeled by assuming *perfect* execution of the second series and a high degree of standardization as well as learning transfer (adjusted by the lever “cross-site transfer efficiencies”) from the first series to the second. Replicating this in the United States is unlikely, but this outcome could be seen as a theoretical lower bound for the projected costs in the United States. This scenario also assumes that the next builds happen on the same site as the first series of builds, which is the case in China, where the second series of builds is happening at the same sites in Sanmen and Haiyang, with perfect site-to-site learning and standardization.

A summary of input levers used in the two scenarios can be found in Appendix A. The results of the cost reduction modeling are shown in Figure 16 with the moderate and optimistic scenarios plotted on a plant/series basis. The WE-FOAK costs are also included in the figure for context. The OCCs in Figure 16 begin to converge between the two scenarios as the series number increases because in the long run, both scenarios would converge with the same NOAK cost. The key difference between the two scenarios is how quickly FOAK costs drop after the first series.

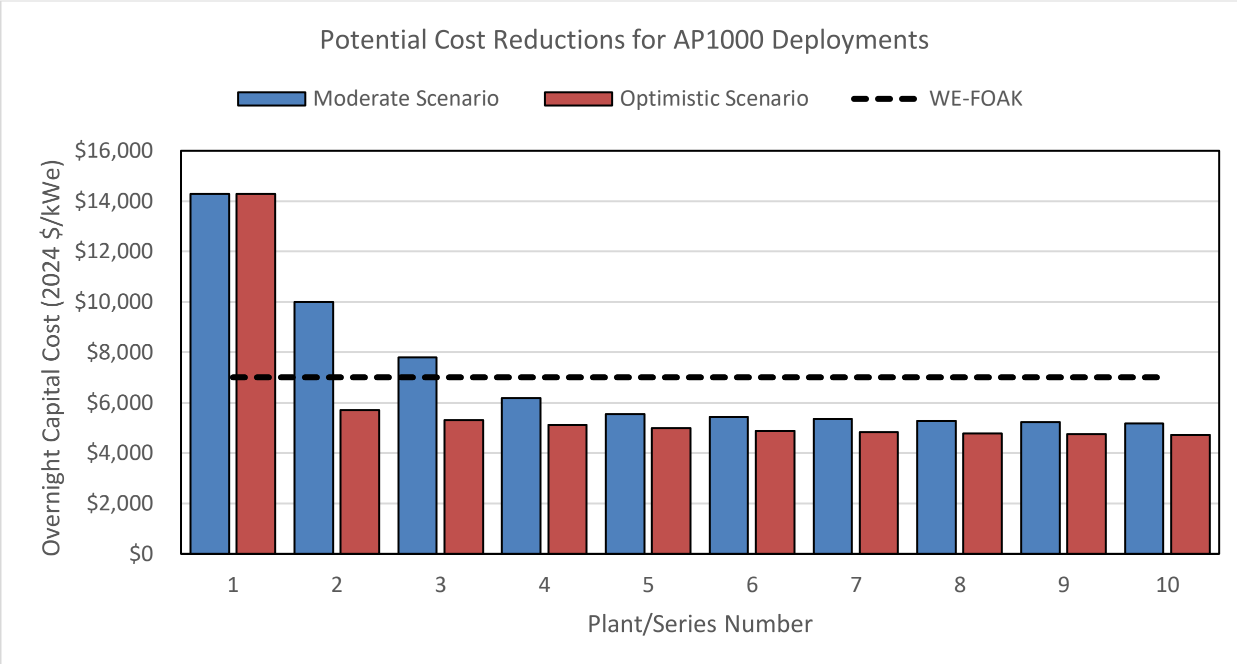

Figure 16. Overnight capital cost reduction curves for moderate and optimistic scenario.

In the moderate scenario (blue bars), the costs drop by approximately 30% from series 1 to series 2 but remain above the WE-FOAK value. The projected greenfield OCC for the second series is $10,000/kWe, which is within the range of $9,300/kWe to $11,625/kWe that was estimated by eliminating some of the overruns in Vogtle Units 3 and 4 caused by a lack of qualified personnel, using a new licensing process, and starting construction with an incomplete design (Shirvan, 2024). However, the cost for series 2 still exceeds the WE-FOAK value, indicating that some overruns[c] will likely persist. By the third series in the moderate scenario, costs closely approach the WE-FOAK values, with only minor overruns, and subsequent series show reductions below the WE-FOAK value, indicating the elimination of overruns and significant learning by about the third or fourth series.

In the optimistic scenario (the red bars), costs decrease more rapidly. From series 1 to series 2, there is an approximate 60% reduction in costs, immediately falling below WE-FOAK, indicating that overruns are immediately eliminated in the second series, and learning is rapidly incorporated. Consequently, there is less cost reduction from series 2 to series 10 compared to the moderate scenario, as most savings are realized between series 1 and series 2. In fact, the costs were reduced by only 17% from series 2 to series 10.

Within the model, cost reductions from FOAK to NOAK can be grouped into two distinct categories. Cost reduction from the elimination of overruns (e.g., rework, poor labor productivity, supply chain delays), and cost reduction from learning by doing. Both categories contribute to cost reductions in each series. Cross-site standardization, which enhances learning by doing, is also accounted for in each series, although it may not be immediately evident if there is a significant amount of overrun. To better illustrate the sources of these reductions, the relative FOAK-to-NOAK cost reductions are categorized in Figure 17 for the moderate scenario.

[c] Overrun here is defined as the difference between the realized cost of the project and the WE-FOAK cost. In practice, overruns are defined as the difference between the realized cost and the project cost estimate at the start of the project. If this project cost estimate accounts for all the risks, it is likely that the overruns will be smaller. However, because cost projections are very uncertain at the beginning phases of the project and are often biased by optimism (Flyvbjerg, Bruzelius, & Rothengatter, 2003), the WE-FOAK cost is used as the baseline to define overruns in this study.

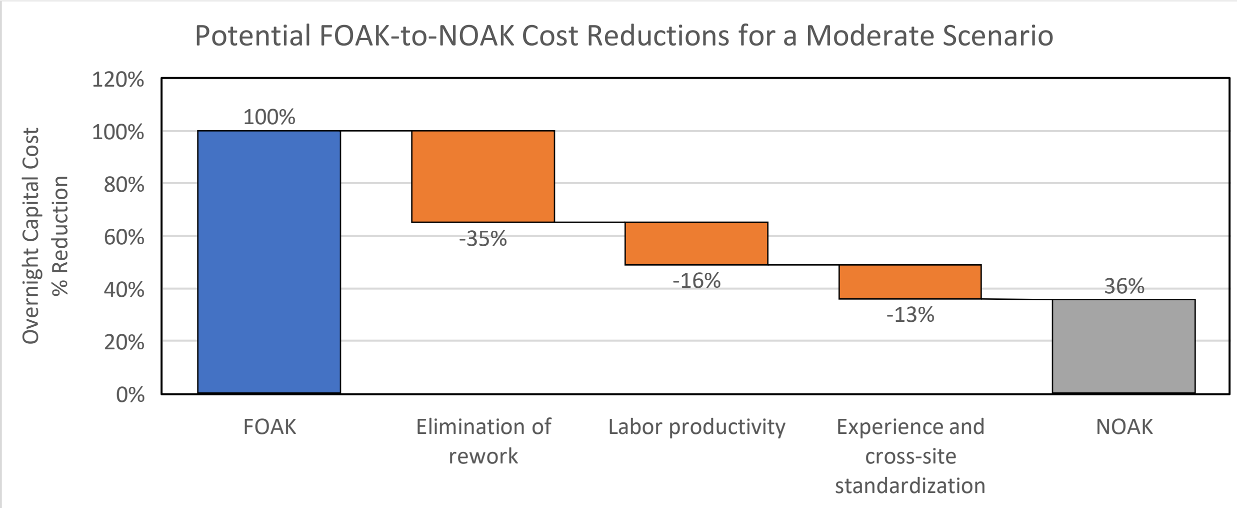

Figure 17. FOAK-to-NOAK cost reduction categories for the moderate scenario.

Of the three categories shown in Figure 17, elimination of rework is the largest contributor to FOAK-to-NOAK reductions, accounting for 35%. This outcome is intuitive, as the Vogtle project experienced a substantial amount of rework. Labor productivity, which accounts for trained workforce availability, and reduced attrition, results in a 16% reduction. Learning from experience, which is amplified for more standardized plants, contributes to 13% of the FOAK-to-NOAK cost reduction. Therefore, in the case of AP1000s in the United States, a majority of the FOAK-to-NOAK reductions such as eliminating overruns can be achieved by leveraging the lessons learned from one project to another. Note that although supply chain improvements are not explicitly named as a source of savings in Figure 18, their impacts are still included. The cost reduction tool specifically models improvements to engineering, procurement, and construction separately. Improvements to each are captured in the total reductions shown herein, although not specifically labeled.

As discussed earlier, cost and schedule reductions go hand in hand. Decreasing the time that it takes to build a plant is vital to reducing financing costs and the labor and overhead costs associated with maintaining such a large construction site. Given this, the cost reduction model also predicts how project duration is impacted by learning. The result of this modeling is shown in Figure 18. Note that in this figure, project duration is split into construction duration and startup duration. Construction duration represents all activities from first nuclear concrete to finishing construction (i.e., placing the top head as illustrated in Figure 4), while startup represents all testing done from the end of construction to commercial operation. The sum of both constitutes the project duration.

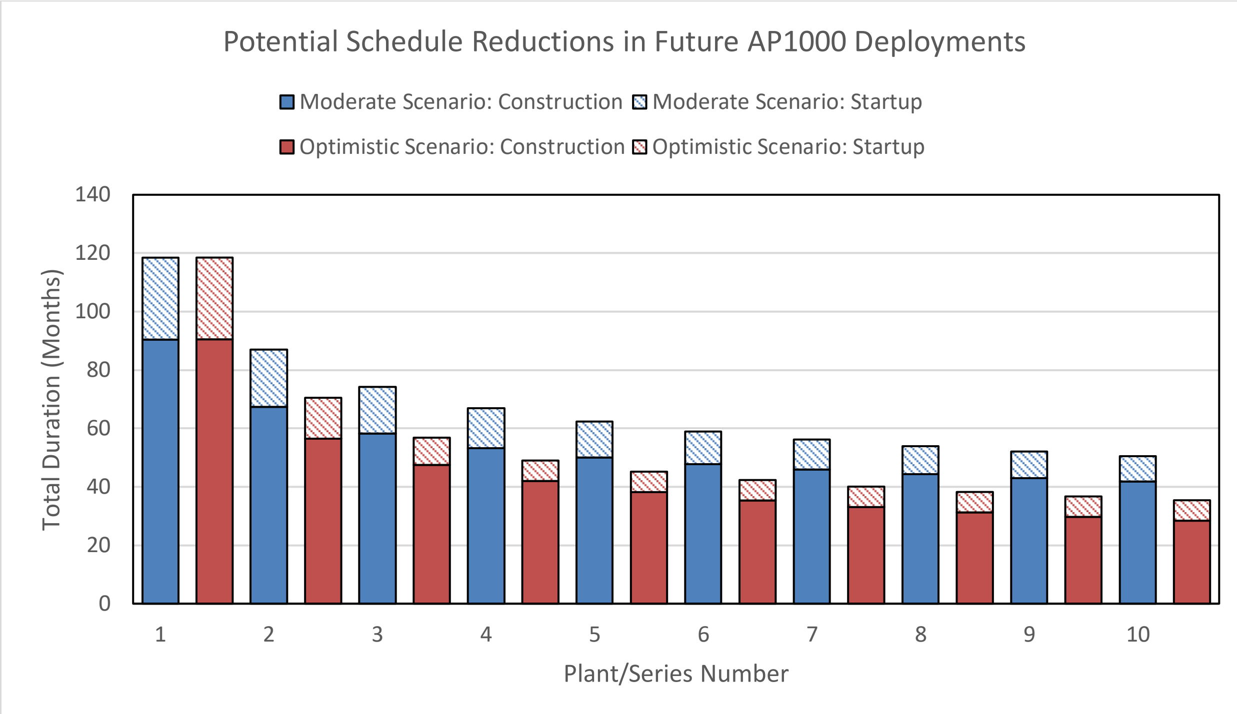

Figure 18. Project duration reduction curves for moderate and optimistic scenarios.

Figure 18 tells a similar story to Figure 16. Both scenarios converge over time, but the optimistic scenario shows more significant schedule reductions earlier than the moderate scenario. The duration of the next build again follows Shirvan (2024) in the moderate case (80–96 months vs. 88 months) and the Chinese experience in the optimistic case (70 months vs. 4–5 years). Overall, schedule reductions from FOAK to NOAK are projected to be significant, being 70% in the optimistic scenario and 57% in the moderate scenario. However, these reductions are expected to converge to NOAK duration values as the series number increases.

Some view the higher-than-expected FOAK costs as evidence that nuclear energy, or specifically this reactor design, is unviable in current or future energy markets. However, this modeling indicates that these high initial costs can be mitigated with diligent engineering and management improvements that require upfront capital investments from reactor vendors, plant owners, and EPC contractors. Consequently, those with a long-term perspective on nuclear energy costs should recognize that AP1000 costs have a pathway to reduction in cost and schedule, enabling the AP1000 to be more competitive in broader energy markets. The most expensive plant in this pathway is the FOAK plant, which has already been built.

To further contextualize this reduction pathway, a levelized cost of electricity (LCOE) calculation was done using the OCC and construction duration values shown above and then compared to the reported LCOEs of other technologies. The LCOE estimation method followed the methodology used by the *DOE Liftoff Report* (Department of Energy, 2024).[d] The resulting LCOE curves are plotted in Figure 19. LCOEs for firm photovoltaics (PV), or PV with storage, are presented for different markets due to LCOE of PV being highly dependent on regional conditions that impact capacity factor. An LCOE for gas

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[d] The LCOE calculations assume the same costs and operational values as the *Liftoff Report*. This includes fuel ($0.66/MMBTU), fixed O&M ($152/kW-year), variable O&M ($2.47/MWh), capacity factor (93%), debt to equity ratio (80:20), cost of debt (5%), cost of equity (9.5%), tax rate (25.7%), inflation rate (2.5%), capital recovery period (30 years), MACRS schedule (15 years), and ITC level (40%).

combined cycle is also included. A more comprehensive study could analyze LCOE sensitivities of these technologies but is beyond the scope of this work. A range for nuclear power is provided, showing costs with and without the inclusion of an investment tax credit (ITC).

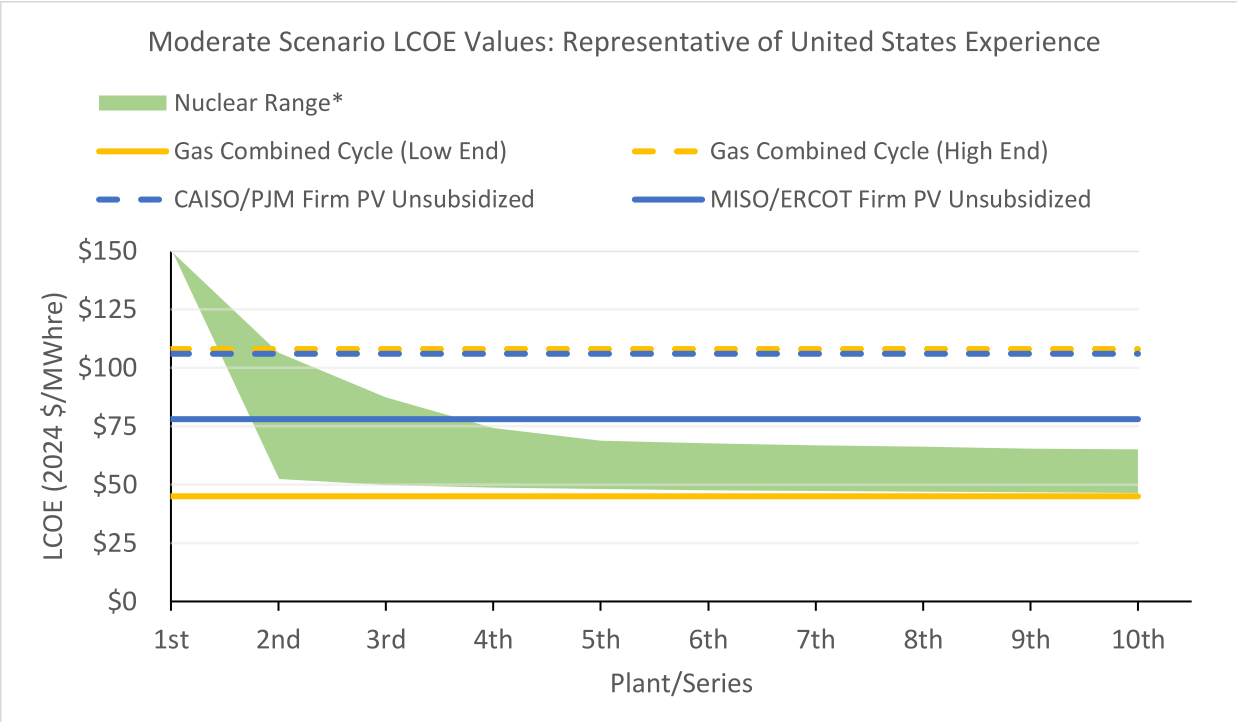

Figure 19. Nuclear energy LCOE evolution and comparison. Key: *The nuclear range is defined as the moderate scenario with a 40% ITC (the lower bound of the range) and without the ITC (the upper bound of the range).

With the inclusion of an ITC, nuclear power nears the low-end values for gas combined cycle[e] by the second series (i.e., the next deployment). By the tenth series, nuclear power is within $1/MWh of low-end gas combined cycle. Without an ITC, it remains ~$20/MWh above the low end but is competitive with the low end by the second series. When compared to unsubsidized firm PV, the time it takes for nuclear power to become competitive is dependent on the region[e]. For the CAISO/PJM region, nuclear power is competitive with or without an ITC by the second series. For the MISO/ERCOT region, nuclear power becomes competitive by the fourth series without ITC.

The ITCs modeled herein represent the investment tax credit created in the Inflation Reduction Act of 2022. This work specifically models the Section 48E, Clean Electricity Investment Credit. This credit is set to phase out starting in 2032, or when annual U.S. GHG emissions from electricity production are equal to or less than 25% of GHG emissions in 2022, whichever occurs later (United States 117th Congress, 2022). This modeling suggests that after the fourth series, nuclear power may be able to compete with both highlighted technologies without an ITC. This is particularly useful when comparing against unsubsidized firm PV, where both technologies receive no subsidies. LCOE values from the first, second, third, and tenth series are shown in Table 8. These are rounded to the nearest dollar.

[e] LCOE for gas combined cycle and firm PV by region is sourced from (Lazard, 2024).

Table 8. Levelized cost of electricity for AP1000s under different cost reduction scenarios.

	Moderate Scenario Representative of United States Experience		**Optimistic Scenario** Representative of the Chinese Experience	
Plant/Series	With 40% ITC	Without ITC	With 40% ITC	Without ITC
1st	$96/MWh	$150/MWh	$96/MWh	$150/MWh
2nd	$72/MWh	$106/MWh	$52/MWh	$71/MWh
3rd	$61/MWh	$87/MWh	$49/MWh	$67/MWh
10th	$49/MWh	$65/MWh	$46/MWh	$61/MWh

Ultimately, the cost and schedule reductions for AP1000 plants shown herein underscore the potential viability for future builds. The data from Vogtle Units 3 and 4, along with evidence and forecasts from the Chinese experience, demonstrate that cost reductions are possible and potentially significant. The results of moderate and optimistic modeling scenarios highlight how substantial these improvements could be and the pace at which they could be realized. These projections suggest that if the AP1000 design is consistently built, while transferring and implementing lessons learned between projects, the competitive positioning and financial viability of this reactor design will only improve. While projecting costs inevitably includes some level of uncertainty (factors such as local labor rates and regional regulations can drive costs up or down), the key takeaway from this modeling is that cost reductions for AP1000s are likely to be both significant and immediate. The competitiveness of nuclear energy is not limited to a distant future where hundreds of plants are needed to achieve cost competitiveness. It may, in fact, be quite close, with only three to five plants needed to become competitive.

6. POTENTIAL SOLUTIONS TO ENABLE EXPANDED NUCLEAR DEPLOYMENT

Many of the challenges identified in this report are not surprising, but rather they represent the remaining hurdles for today’s designers and potential stakeholders. It is clear that cost and schedule reductions can be achieved by implementing the lessons learned from previous experience. However, several solutions will need be pursued to enable the implementation of learning and help overcome the risks from FOAK deployments easier for the industry. A non-comprehensive list of these solutions and potential research areas is below:

- **Supply chain and workforce availability:** The U.S. AP1000 projects highlighted significant issues with supply chain and workforce shortages, leading to delays and increased costs. These challenges still remain pressing for the deployment of future AP1000s and other advanced nuclear power plants. To enable the expanded deployment of nuclear, both the supply chain and workforce will need to be improved and expanded and industry organizations such as the Nuclear Energy Institute (NEI) and the Electric Power Research Institute (EPRI) as well as reactor vendors have been making efforts in this regard. Vogtle and V.C. Summer projects adapted the non-nuclear supply chain by modifying factories that supplied to the oil and gas industry to produce structural modules for the reactor building. However, modules built in these factories required a significant amount of rework due to improper implementation of quality requirements. Developers of upcoming advanced reactors also plan to similarly leverage the non-nuclear supply chains. To avoid similar challenges in the future, the following solutions could be pursued:

  - Outreach efforts are needed to engage with non-nuclear suppliers that can potentially fill critical gaps in the U.S. nuclear supply chain. Given that nuclear quality requirements can be significantly different from non-nuclear quality requirements, efforts are needed to "bridge the gap" between nuclear and non-nuclear quality programs to make the barrier between these supply chains more porous.
  - Similar to supply chain issues, efforts are needed to train and certify a workforce for nuclear-related craftsmanship. Much of the workforce might again come from the non-nuclear industry, but the significantly different requirements in nuclear makes this a more difficult transition. Workforce programs are needed that focus on enabling the non-nuclear workforce transition into the nuclear industry, in addition to training a new workforce from scratch.
  - Research and development (R&D) and innovations like digital engineering and digital twins for construction, construction robotics for cost-intensive on-site labor activities (e.g., welding), automated inspections, etc., can also help adapt to workforce shortages.
  - Metrics and predictive models are needed to assess the readiness and reliability of supply chains and workforce capabilities. These metrics, benchmarked with past nuclear and non-nuclear projects, could be beneficial for avoiding such issues in future projects.

- **Risk-informing contracting structures:** Several contractual disputes and misaligned incentives contributed to cost overruns and delays. Investigating alternative contracting strategies and risk-sharing mechanisms that align incentives with risk exposure and reduce potential conflicts and cost overruns will be critical for future projects. New contracting models should be evaluated for their effectiveness in promoting collaboration, transparency, and shared responsibility among project stakeholders. Upcoming business models (e.g., the developer model that involves taking full responsibility for the project from start to finish and integrates learning into future projects, or the EPC model that involves EPC-owned and built plants) could also be explored from a risk exposure perspective.
- **Integrated Project Delivery (IPD)**: Project management for megaprojects such as AP1000 or other nuclear construction requires ensuring all the participating parties (i.e. reactor designer, EPC, suppliers, etc.) deliver for a successful project. Therefore, as suggested in the *DOE Liftoff Report* (Department of Energy, 2024), an IPD approach that provides a framework for aligning financial incentives and improve coordination between the owner and their contractors. Learnings and intellectual property could be shared across the IPD team to deliver projects on-time and on-budget.
- **FOAK testing and demonstrations:** The lack of constructability and subsequent rework in the steel-composite structural modules in AP1000 serve as an example of FOAK construction issues. These issues could be avoided through field-scale demonstration and testing, not just for construction technologies but for other aspects such as appropriate tooling and tolerance issues. Demonstration projects, such as the Advanced Construction Technologies Initiative (ACTI) led by the National Reactor Innovation Center (NRIC), significantly de-risk FOAK deployments and reduce cost and schedule overruns.
- **FOAK design completion criteria:** Completing design before beginning construction is one of the most standout lessons from the Vogtle project. However, as a FOAK design and construction project, it is not always evident what constitutes a complete design and when construction should begin. As evident when starting the first series of AP1000 construction, it was unclear what the level of design completion was and how big an impact it would have on the results. Development

of clear criteria and methods to evaluate a suitable FOAK design completion level could help de-risk future FOAK deployments.

- **Optimizing QA/QC requirements:** While QA/QC requirements are important for safety, they are not always examined from a constructability or an economics standpoint. These requirements arise not only from the American Society of Mechanical Engineers (ASME) Nuclear Quality Assurance Standard, NQA-1, but also from the engineering and construction codes and standards (e.g., the ASME BPVC [Boiler and Pressure Vessel Code] for pressure boundary components, ACI [American Concrete Institute] for reinforced concrete structures, AISC for steel structures, IEEE [Institute of Electrical and Electronics Engineers] for electrical equipment). Constructability and economics should be a part of the QA/QC requirements development in these codes, which is only possible with active involvement of constructors, fabricators, and design engineers in these code committees.
- **Codes and standards for FOAK designs:** FOAK plants often cannot be designed or built using NRC-endorsed or existing codes and standards since they may not have coverage for specific design instances. Overcoming this involves further testing and analysis on test specimens to reduce licensing risk. Research, testing, and support to overcome these challenges and timely updates to codes and standards can help mitigate issues before they arise. Additional flexibility in using non-nuclear codes and standards for safety-related components will also help remove these barriers and enable faster innovation.
- **Optimized FOAK-to-NOAK deployment timelines:** A noticeable result of starting construction of multiple parallel units is that a single FOAK issue can propagate across multiple units. Therefore, ensuring adequate duration between units can be beneficial in allowing time to identify and transfer lessons and experience from one project to another. Contrarily, if the duration between builds is too long, there can be workforce and supply chain atrophy. Research exploring the economics and logistics of deploying multiple units in a fleet, including the benefits of standardization and economies of scale and developing guidelines to adequately “stagger” consecutive builds to enable efficient transferring of lessons learned, can greatly improve the success of future projects.
- **An industry-wide, coordinated effort on lessons learned:** As seen in the Chinese schedule data, successful transfer of lessons learned from FOAK executions of the AP1000 plants to develop the CAP1000 is resulting in a ~50% reduction in schedule from the first series of AP1000s. Such a transfer of FOAK lessons learned to new nuclear projects is a considerable engineering and regulatory effort. As more plants are built in the U.S., this challenge could be addressed through a larger, industry-wide, coordinated effort to gather and share construction lessons learned. Such a coordinated effort may significantly speed up the U.S. learning experience and reduce cost and schedule of future plants. Similar experience-sharing efforts do exist in the operating fleet, for example, through the Institute of Nuclear Power Operations (INPO).

7. SUMMARY AND KEY TAKEAWAYS

The successful completion of the first domestic AP1000 power plants, Vogtle Units 3 and 4, marks a significant milestone in the resurgence of nuclear construction in the United States. This report analyzes a set of implications of this achievement, by examining the trends in cost and schedule reductions in AP1000 deployments both domestically and internationally. It then uses these trends to evaluate potential cost reductions in the future AP1000 builds in the United States.

The Westinghouse AP1000 is a large light-water reactor with several benefits over its predecessors, including a standardized design, smaller footprint, smaller amount of construction materials and components, modular construction, and passive safety. Adding to these advantages, it retains economies of scale, offering 1.1 GWe of reliable baseload power for likely 80 years. The completion of Vogtle Units 3 and 4, despite significant cost and schedule overruns, provides valuable lessons for future deployments, and by virtue of being FOAK, de-risks these deployments. Some of these lessons include the importance of finalizing the design before construction, conducting constructability reviews, creating integrated project schedules with adequate detail, ensuring robust quality assurance processes throughout the subcontracting chain, and performing adequate project risk assessment.

Empirical data from AP1000, CAP1000, and CAP1400 projects in the United States and China represent a hopeful indication; the analysis results suggest that future nuclear construction could be delivered at lower cost and with greater schedule certainty. Historically, the U.S. nuclear industry has not seen significant cost and schedule reduction from learning. But this can be changed with repeated builds of a standardized design, gathering lessons learned from each project, and making the investments to implement these lessons in subsequent projects. Insights from challenges at Vogtle, Sanmen, and Haiyang helped the creation of CAP1000, which is being constructed almost twice as fast as the first series of AP1000s, illustrating the expected pathway from FOAK-to-NOAK. Even if only a portion of these improvements are implemented in the next U.S. AP1000 builds, tremendous improvements in cost and schedule can be expected.

A cost reduction analysis for future AP1000 deployments in the United States starting from the FOAK cost at Vogtle suggests that with the application of lessons learned, the next three deployments of two-unit AP1000 builds may cost around $10,000/kWe, $7,800/kWe, and $6,200/kWe and take 7 years, 6 years, and 5.5 years, respectively, to build. At these capital cost levels, U.S. AP1000 LCOEs indicate that the reactors could be cheaper than firm battery-supported solar PV, in the MISO/ERCOT region, as well as CCGT (High End), without accounting for the impact of any subsidies. With a 40% ITC or Production Tax Credit (PTC), it is likely that the next AP1000 series in the United States can be attractive in a wide range of markets. These are preliminary, academic projections and not investor-grade predictions for the next AP1000 plants. Nevertheless, they do show that cost reductions in the next AP1000s may be steep, and it may only take a few more plants of consistent deployment for them to become affordable in most markets.

Some of the key findings from this report are as follows:

- **A resurgence**: Vogtle 3 and 4 are the first nuclear plants in the United States in 35 years to start and finish construction. Understandably, these projects faced not just FOAK issues but also “first-in-a-long-time” issues following significant loss in the experience, workforce, and supply chain in the U.S. nuclear industry. The completion of the Vogtle projects marks a resurgence not just for AP1000s but also for all other nuclear technologies. The lessons learned from the Vogtle projects are many and should be applied to all the FOAK plants that are scheduled to be built in the United States in the next decade.
- **Learning has been observed:** The significant reductions in construction timelines and costs between the first and second series of AP1000 projects in China highlight the clear evidence of the tremendous impact of standardization and learning by doing. Given that almost all future plant designs including the AP1000 are highly standardized (unlike the existing fleet in the United States), these cost reductions provide a compelling case for consortium approaches that aggregate demand and place large orderbooks in the future. FOAK plants might be expensive but once finished the costs of next standardized plants may fall sharply and sharing the overruns of the first plants enables everyone to take advantage of the reduced cost of the subsequent plants.

- **Learning is not finished:** Although many lessons have been learned from past AP1000 projects, these lessons in themselves are not enough to achieve the magnitude of cost reduction shown in this study. Lessons learned may not fully transfer until substantial efforts are made in subsequent projects, to improve processes and design, such as those seen in the transition from China's AP1000 to CAP1000. As seen in other industries, learning is a process of continuous improvement, where evaluation and application of best practices is essential to achieving steady reductions in cost and schedule for future AP1000 and other nuclear power plant builds. One approach to achieving this in a private nuclear industry like in the United States, is to have a coordinated, industry-wide effort to gather and share lessons learned from future nuclear construction projects.
- **In-series vs. series-to-series learning:** Cost and schedule reduction due to learning were observed between Vogtle 3 and 4. Evidently, Unit 4 was 15–20% cheaper. However, experience from both domestic and international deployments shows that plants of the same design constructed in parallel have significant interdependencies in their supply chains and management, and challenges in one unit or plant can easily impact the cost and schedule of another. A more significant amount of learning and cost reduction is likely between different series of builds, only if an adequate amount of gap is provided between these series so that learning can be transferred and implemented. With this in mind, and looking at the Chinese data, it is likely that the cost of the next AP1000 build could decrease much more than that 15–20% achieved from Units 3 to 4, even up to 50% as seen in China.
- **Missing the resurgence:** While a small gap between build series might be beneficial to enable the efficient transfer of lessons learned, too large a gap might again result in an atrophy of the supply chain and workforce that was built for the Vogtle plants. With no publicly firm orders for AP1000 plants at the time of writing this report, the United States is at a risk of losing this supply chain and workforce knowhow. This might lead to a repeat of the "first-in-a-long-time" issues in the next series of builds.

In closing, the future of nuclear construction appears very bright. Vogtle's completion and China's subsequent scaling-up of AP1000 builds have collectively shown that a path forward to success exists. If the strategies outlined in this and other reports are implemented, building on the success of recent AP1000 experiences, new nuclear projects can be expected to be delivered with reduced cost, schedule, and their associated uncertainty.

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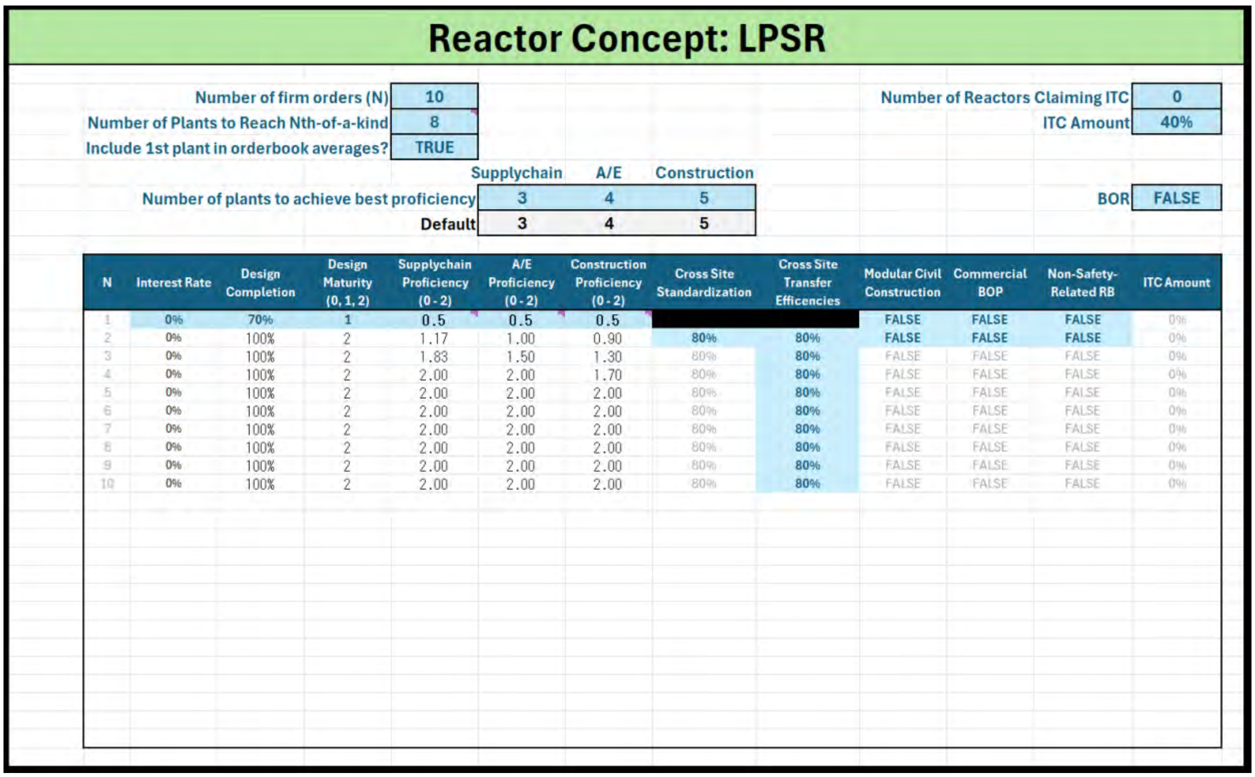
APPENDIX A

Inputs for Cost Reduction Modeling

The figures below show screenshots of the dashboard of the cost reduction framework for the modeling the two scenarios: moderate scenario representative of U.S. experience and an optimistic scenario representative of Chinese experience. The dashboards show the input levers used to model these scenarios. Note that LPSR refers to the large passively safe reactor modeled in Stewart and Shirvan (2022) that is similar to the AP1000. Since the WE-FOAK estimate already includes modularity, it is not modeled again in the framework and the corresponding lever is set to FALSE. Rows 1 to 10 indicate the levers for the 1st to 10th plants. BOR indicates bulk order reduction as defined in Bolisetti et al (2024) and is not modeled in these cost reduction scenarios.


Reactor Concept: LPSR

Number of firm orders (N)	10
Number of Plants to Reach Nth-of-a-kind	8
Include 1st plant in orderbook averages?	TRUE
Number of Reactors Claiming ITC	0
ITC Amount	40%
BOR	FALSE

	Supplychain	A/E	Construction
Number of plants to achieve best proficiency	3	4	5
Default	3	4	5

N	Interest Rate	Design Completion	Design Maturity (0, 1, 2)	Supplychain Proficiency (0 - 2)	A/E Proficiency (0 - 2)	Construction Proficiency (0 - 2)	Cross Site Standardization	Cross Site Transfer Efficencies	Modular Civil Construction	Commercial BOP	Non-Safety-Related RB	ITC Amount
1	0%	70%	1	0.5	0.5	0.5			FALSE	FALSE	FALSE	0%
2	0%	100%	2	1.17	1.00	0.90	80%	80%	FALSE	FALSE	FALSE	0%
3	0%	100%	2	1.83	1.50	1.30	80%	80%	FALSE	FALSE	FALSE	0%
4	0%	100%	2	2.00	2.00	1.70	80%	80%	FALSE	FALSE	FALSE	0%
5	0%	100%	2	2.00	2.00	2.00	80%	80%	FALSE	FALSE	FALSE	0%
6	0%	100%	2	2.00	2.00	2.00	80%	80%	FALSE	FALSE	FALSE	0%
7	0%	100%	2	2.00	2.00	2.00	80%	80%	FALSE	FALSE	FALSE	0%
8	0%	100%	2	2.00	2.00	2.00	80%	80%	FALSE	FALSE	FALSE	0%
9	0%	100%	2	2.00	2.00	2.00	80%	80%	FALSE	FALSE	FALSE	0%
10	0%	100%	2	2.00	2.00	2.00	80%	80%	FALSE	FALSE	FALSE	0%

Figure A-1: Cost reduction levels for the moderate scenario, representative of United States experience.

Reactor Concept: LPSR

Number of firm orders (N)	10
Number of Plants to Reach Nth-of-a-kind	8
Include 1st plant in orderbook averages?	TRUE
Number of Reactors Claiming ITC	0
ITC Amount	40%
BOR	FALSE

	Supplychain	A/E	Construction
Number of plants to achieve best proficiency	1	1	1
Default	3	4	5

N	Interest Rate	Design Completion	Design Maturity (0, 1, 2)	Supplychain Proficiency (0 - 2)	A/E Proficiency (0 - 2)	Construction Proficiency (0 - 2)	Cross Site Standardization	Cross Site Transfer Efficencies	Modular Civil Construction	Commercial BOP	Non-Safety-Related RB	ITC Amount
1	0%	70%	1	0.5	0.5	0.5			FALSE	FALSE	FALSE	0%
2	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
3	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
4	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
5	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
6	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
7	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
8	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
9	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%
10	0%	100%	2	2.00	2.00	2.00	100%	100%	FALSE	FALSE	FALSE	0%

Figure A-2: Cost reduction levels for the optimistic scenario, representative of the Chinese experience