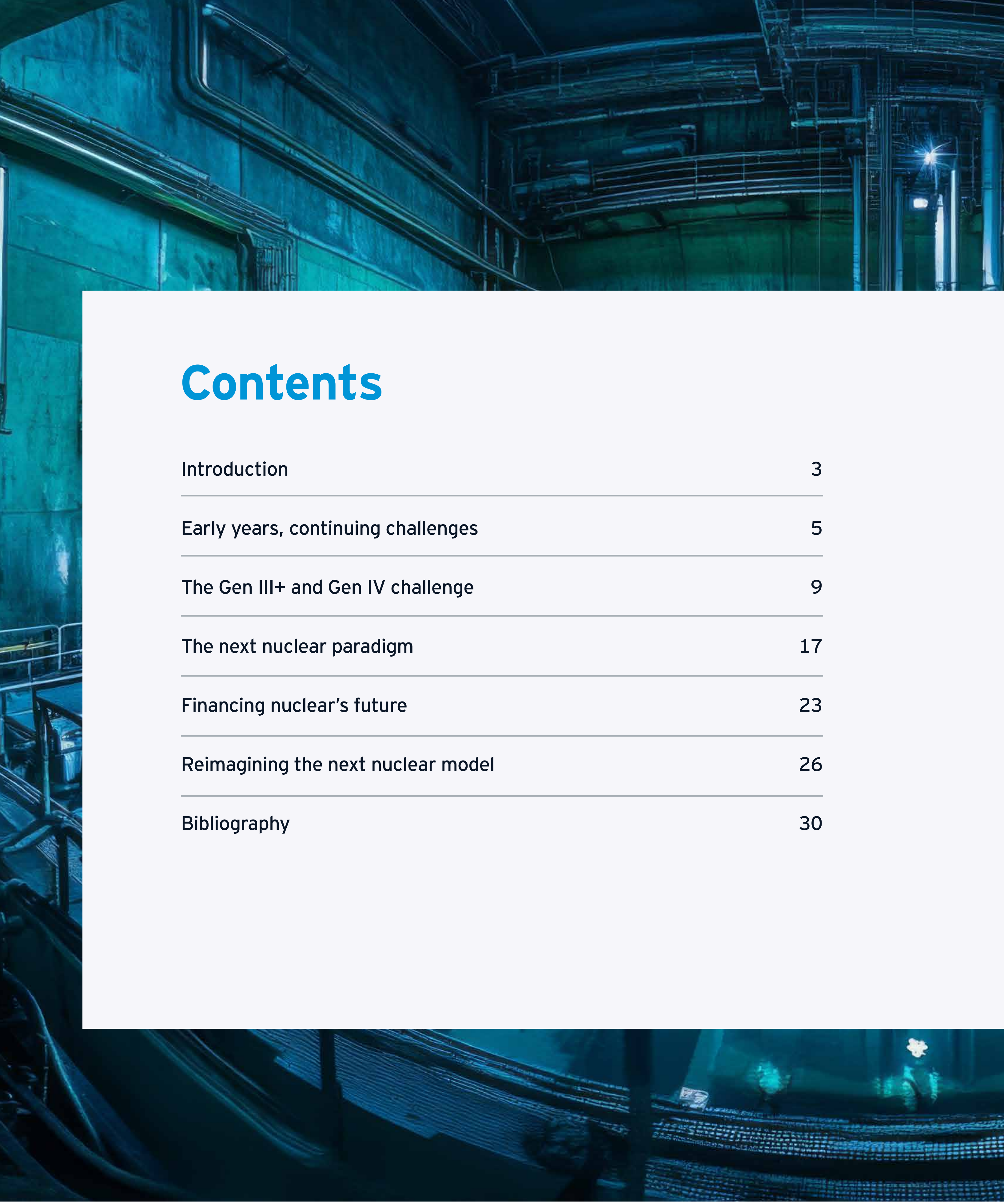
Nuclear's next chance

Getting future projects right

The better the question. The better the answer.
The better the world works.

EY Parthenon
Shape the future with confidence



Contents

Introduction 3

Early years, continuing challenges 5

The Gen III+ and Gen IV challenge 9

The next nuclear paradigm 17

Financing nuclear's future 23

Reimagining the next nuclear model 26

Bibliography 30

Introduction

Growth expectations for the nuclear sector typically start with great promise for the future, reflecting a belief that prior lessons learned have been thoroughly studied and incorporated into the next project, even if years pass between the last plant and the next one. But these hopes are consistently dashed by both controllable and uncontrollable adverse circumstances similar to prior unsatisfying eras. Each time a new nuclear renaissance looks possible, events arise that constrain its progress.

From the late 1970s through the 1980s, economic conditions, including high interest rates, were not hospitable to financing costs. In addition, the Browns Ferry Nuclear Plant fire and the partial core meltdown at Three Mile Island Nuclear Generating Station upended existing U.S. Nuclear Regulatory Commission (NRC) standards and requirements. Together, these factors adversely impacted the commercial operation date (COD) for dozens of underconstruction nuclear plants, resulting in sector-wide delays, some of which extended over a decade.

But increased regulation and higher interest rates were not the sole causes of skyrocketing costs and mounting delays. Owners of nuclear projects frequently suffered internal process failures in project management, design readiness, production performance and quality assurance, which exacerbated already uncertain project outcomes. Generation II (Gen II), Gen III (1965–87) and Gen III+ (2006–24+) projects consistently had process failures that drove nuclear power from being too cheap to meter to being too expensive to undertake.

During the abbreviated nuclear renaissance of the early 2000s, more than a dozen proposed US nuclear plants were at some stage of early development and licensing, but the trend wilted to only two plants advancing to construction, one of which was ultimately terminated.

To be fair, these management, design and construction problems were not solely limited to nuclear plants; most megaprojects (i.e., those over $1b), across industries were plagued by poor estimating, development, execution and management, requiring remediation and expensive tear-out, rework and delay.

Today, tailwinds including a congruence of federal policy, positive consumer sentiment, power supply needs, clean energy priorities and technology advancements are shaping more favorable sector conditions than in any period over the last three decades. Supportive sentiment from all corners is at its highest since the 1960s, with once-adverse stakeholders recognizing the need for nuclear in the country's future power supply. Potential new nuclear owners are already looking at the future new-build environment in a different way. They are thinking about how to build smaller plants and differently about how to develop and construct this future generation of plants, or "next nuclear."

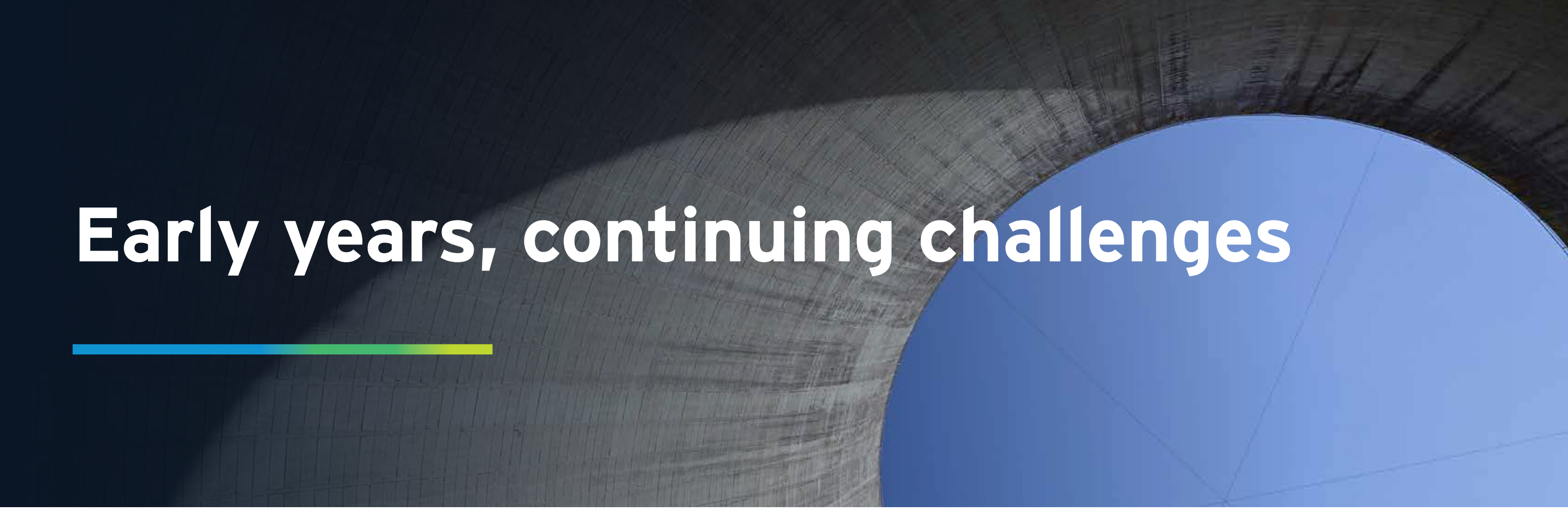
While this study focuses on new nuclear in the US, Europe's nuclear landscape is progressing at a faster pace as several countries face the dual challenge of replacing aging reactors and scaling up new plants to meet energy security and decarbonization goals. Pro-nuclear nations such as France, the United Kingdom (UK) and Finland are advancing regulatory frameworks and accelerating investments, while phase-out countries such as Germany and Belgium focus on renewables. Nevertheless, the war in Ukraine has reframed energy security as an urgent priority across Europe, driving several countries to revisit or expand nuclear plans.

The European Union's inclusion of nuclear power in its sustainable finance taxonomy offers a pathway to attract green financing under strict conditions, yet private investors remain hesitant. This challenge — like that in the US — highlights the delicate balance between enabling affordability for taxpayers and achieving the long-term strategic benefits of nuclear energy in the global clean energy transition.

In the US nuclear sector, it is past time for all players; Congress; the NRC; state regulators; owners; fuel suppliers; original equipment manufacturers (OEMs); engineering, procurement and construction contractors (EPCs); specialty fabricators; contractors; and investors — to align on an aspiration for next nuclear that is conceived, financed, enabled and delivered to facilitate better outcomes.

All these entities need to address historical project shortcomings and approach the next era of projects from a fundamentally different perspective. This view emphasizes standard "big box," small modular reactor (SMR) and micro-reactor designs that enable fleet models, embed fully integrated planning and management, adopt imaginative methods to mitigate historical risks, and reflect a mindset of sustaining and accelerating from a single first-of-a-kind (FOAK) plant design to a continually expanding fleet, ultimately reflecting desired next-of-a-kind (NOAK) economics.

To bring a new generation of nuclear plants to market, fundamental changes to planning, construction, delivery and management models are needed. Lessons from the past and those that come with new and ongoing planning and construction regimes can enable sustained economies of scope (design) and scale (volume) in nuclear energy development.



Early years, continuing challenges

In the formative years of large-scale nuclear development, in the mid-to-late 1960s, more than 50 reactors were announced in the US. The reactors were sponsored by utilities large and small, and the belief was that the industry could deliver on its promise to deliver plants where the energy would be too cheap to meter.[1]

Even as the utilities sector coalesced in earlier years around the enthusiasm for "going nuclear" and the design concept appeared clear, full understanding of current and future implications was not fully adequately embraced. One early — and pivotal — outcome regarding the development of a robust nuclear future for the utilities industry was the entry of competitive reactor engineering firms that offered multiple options for nuclear steam supply systems (NSSS).

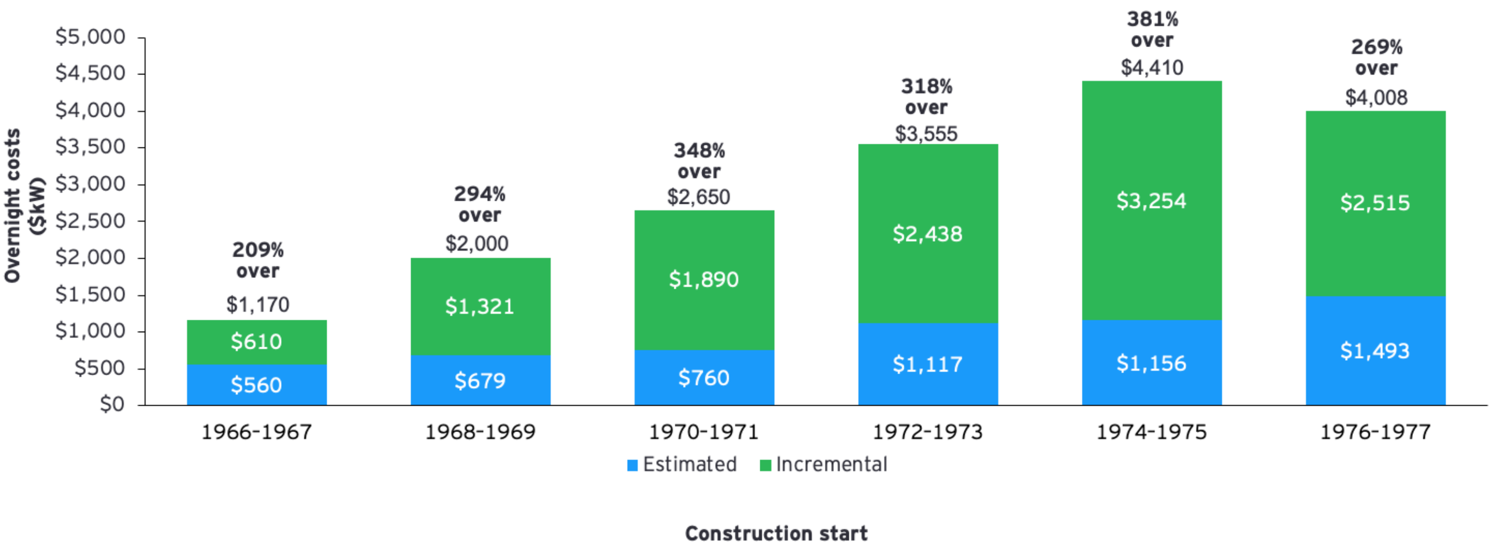
Large, well-known OEMs offered design options with different technologies to meet owner utility needs. These included pressurized water, boiling water and high-temperature gas-cooled reactors, etc., which created both a benefit and eventual challenge.

Even when a specific reactor option was selected, standard design models were not broadly adopted; rather, they were viewed as menu options to owners. This allowed utilities to request design and operating changes to fundamental design, leading to owners continually asking OEMs (and the NRC) for tweaks to fulfill unique needs of specific utilities, including configuration for maintenance, additional safety features and fuel characteristics. Thus, a few standard reactor designs proliferated into dozens of unique models and created continuous cost and schedule challenges.

While these initial projects, which reflected different and competing reactor technologies, were heralded as the future of nuclear power generation, cracks in project delivery began to appear shortly after the start of construction. Design completion and construction costs outran planned levels, and delivery dates became further extended.

The range of changes to estimates between 1967 and 1969, which doubled across in-flight plants, had tripled by 1971. (See Figure 1)

Figure 1: Historical Gen II experience
Gen II impact summary, cost projections vs. realized costs



Source: U.S. Department of Energy, U.S. Energy Information Administration, "An Analysis of Nuclear Plant Construction Costs," 1983.

In the mid-1970s, a seminal nuclear sector event – the Browns Ferry fire emergency – elevated NRC concerns about fire protection and began the era of closer regulatory oversight and continuous changes to existing standards and requirements.

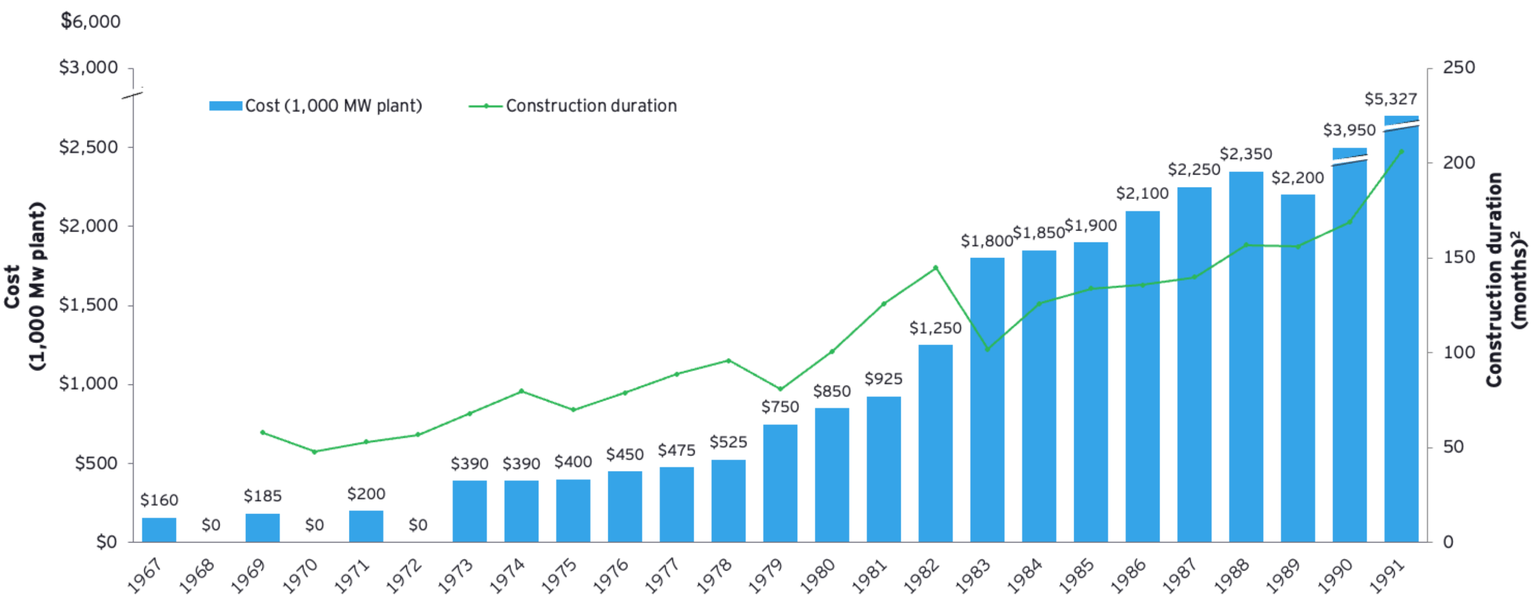
This event caused costs to continue to increase, as significant design changes were made after construction had started on plants. In addition, the complexity of plant scale and moving regulatory targets began to permeate owner core designs, project management and construction delivery.

When Three Mile Island experienced a partial core meltdown at Unit 2 in 1979, the industry was shocked and immediately on its back foot, with NRC focus shifting from general design and construction to targeted remediation and prevention. As public sentiment soured on nuclear and became acutely concerned with plant safety, the NRC reacted and doubled down on its design assessments. It required broader and deeper probabilistic risk analyses, strengthened fundamental materials and structures, increased safety measures, enhanced presence of onsite inspectors, and improved reactor operating training. This fueled a licensing environment where public intervention over design quality, safety features and plant operator training became a cottage industry and single-handedly contributed to years of rework and schedule delays.

The trend in cost overruns and schedule slippage continued through the early 1990s when the last of the ongoing 1970s vintage plants were finally completed – after a decade of delay to COD from regulatory changes and construction underperformance. Cost estimates quickly doubled compared with original estimates and continued upward, almost quadrupling. And construction durations, measured as post-construction permit activity through COD, still extended durations to over 200 months. (See Figure 2)

Figure 2: Gen II construction performance

Cost escalation and schedule extension



Source: U.S. Department of Energy, Nuclear Energy Cost Data Base doe/ne–DO/NE 0044/2 DE-84 010609 "A Reference Data Base for Nuclear and Coal-fired Powerplant Power Generation Cost Analysis ", March 1984; U.S. Department of Energy: Office of Scientific and Technical Information; U.S. Department of Energy, Energy Information Administration, "An Analysis of Nuclear Plant Construction Costs, DOE/EIA 0485, 1983; U.S. Nuclear Regulatory Commission, Nuclear Power Plants and Construction Status Report NUREG 0030, Vol. 6, No.2; June 30, 1982

This level of subpar execution had three distinctive outcomes: it bankrupted the reservoir of public support for nuclear; eviscerated the potential for nuclear recovery of the sector for almost 15 years and extended a lingering dark cloud over the early 2000s attempt at a nuclear resurgence.

But it was not just the macro-level outcomes that saddled the nuclear sector with historical baggage. It was how these outcomes materialized that created public, owner, federal government and local regulator doubt about the ability to avoid challenges in the future. For decades, the challenges of Gen II and Gen III nuclear performance and management gaps were left unattended and unsolved, only to recur later.

The nuclear industry realized that nuclear sector performance from the early 1970s to the early 1990s was not the result of a single failure. Rather, plant design standards were not rigorously imposed and critical design and delivery processes that could fail did, sometimes spectacularly, and often in tandem with related causative factors.

Numerous observers developed studies of earlier eras to define the major drivers and causation factors related to lessons learned and remediation actions to prevent recurrence. But studying problems is far different from implementing the right corrective actions, gaining control over the most critical impediments, and recognizing how pervasive common issues impacted many individual nuclear projects.

The list of nuclear design, construction, management and quality assurance problems in the Gen II and Gen III era is pervasive and long, but tends to center on the industry's inability to emphasize several key fundamentals: make standard plant design a critical underpinning; stabilize design prior to construction; integrate the OEM, EPC and specialty fabricators and contractors; implement effective owner project management; and adhere to rigorous quality assurance programs. (See Figure 3)

Figure 3: Gen II project root causes and consequences

Factors affecting projects

- Multiple plant and design options
- Incomplete and changing designs
- Unfounded expectations
- Labor shortages and churn
- Lack of experienced EPCs and contractors
- Ineffective project management
- Cost-plus contracting
- High interest rates
- First-time NRC licensing approach
- Arbitrary regulatory decisions
- Emphasis on cost and schedule over quality
- Difficult to obtain qualified crafts
- Poor construction discipline

Project consequences

- Proliferation of nonstandard units
- Drawing redesign and rerelease
- Reissue of work packages for constructability
- Significant tear-out and rework
- Poor field productivity across the crafts
- QA process revamping of procedures
- Late owner resource additions to project controls
- Risk analysis addressed after the fact
- NRC prone to issuing "stop work" notices
- As-built gaps requiring re-documentation
- Project management integration lagged key stages
- Continuing gaps in relevant project experience
- Loss of regulatory confidence for future projects

Source: EY-Parthenon analysis

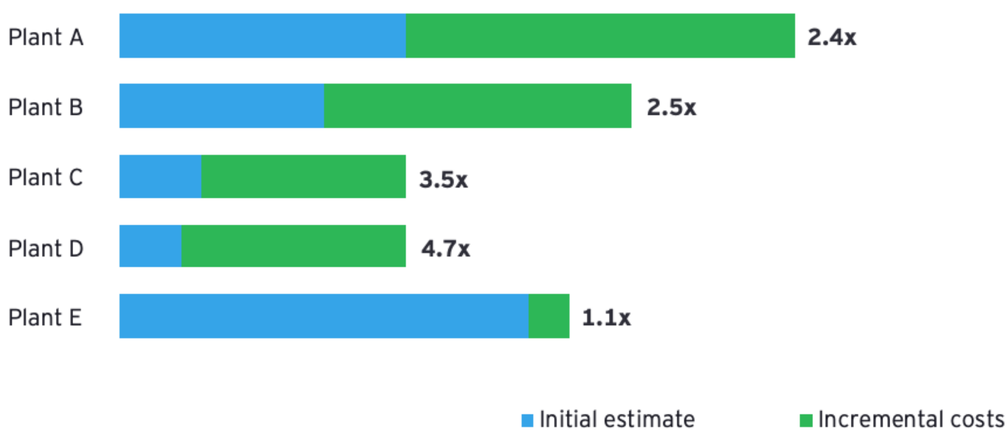
EPCs = Engineering, procurement and construction; NRC = Nuclear Regulatory Commission; QA = quality assurance

Yet three decades after the problems of the Gen II and III era, these same problems resurfaced in Gen III+ projects. These featured light water reactors with design enhancements in thermal efficiency, safety features, standard designs, etc., in the few western country projects that were developed and brought to COD over the last 20 years in the US, France, UK, Finland or the United Arab Emirates (UAE).

Failures to adequately address the most common design adoption and construction problems led to the same level of cost overruns and schedule slippage, only on a far larger plant platform. The most common failures were design and construction complexities, contractor performance and quality assurance gaps, as well as the special international challenges of training and integrating a workforce of many nationalities, languages and norms.[2,3,4,5] (See Figure 4)

Figure 4: Gen III+ project outcomes

Recent projects (estimated to final cost change)



Source: EY-Parthenon analysis of industry and government reports

Once again, the deployment of multiple reactor design choices carried with it the costs of initial indecision and changes later in the plant design and construction cycles. More importantly, the availability of lessons learned was foregone as the designs were largely bespoke to meet country and owner needs in the US, UK, France, Finland and UAE.

Across the 60-year time frame of nuclear project development and execution, there have been five deadly sins for nuclear power, regardless of technology generation: 1) pursuing too many discrete design options; 2) constant changing reactor and plant design; 3) the consistent lack of experienced resources, including management, vendors, contractors, indirect labor or craft labor; 4) the inconsistent execution of quality assurance programs; 5) and the general unfounded industry overconfidence resulting in a profound lack of continuous risk analysis across the nuclear sector. Even one or two of these shortcomings are a significant detriment to plant development and construction success. All of them in concert can be fatal.

However, not all plants experienced runaway project costs and extended COD schedules. A recent international nuclear project had better outcomes at a multiunit facility with construction durations of less than 10 years for each commonly designed and delivered plant, though original COD schedules became extended.[6] This project, with large-scale, continuous construction, and a stable workforce, benefited from economies of scope and scale.

This recent collective project experience does not offer solace to potential investors, who have to continuously consider the merits of whether to invest in new nuclear. Going forward, owners building plants must direct attention to simplifying reactor options and clarifying how they are reducing risk for potential investors.

The lack of imaginative and committed "what if" risk assessment illustrates a critical element of industry hubris and a fundamental flaw in project management. Comprehensive and detailed risk analyses – with commensurate identification of risk mitigation measures – were not commonplace and often a difficult action to persuade owners to undertake.

It is critically important for the industry to recognize what may be even larger problems on the horizon: there are far fewer experienced OEM, contractor, indirect and direct labor resources across the sector than in prior eras; SMR technology adoption and development are FOAK and the learning curve for these technologies is yet to be broadly validated; no effective funding backstop exists to support initial cost overruns in early plants; most reactor OEMS are underfunded and underresourced; and the risks related to new plant designs, both technical efficacy and outcome predictability, have yet to be fully vetted.

Next nuclear depends on resolving these challenges by developing thoughtful and workable solutions before projects take off, not while they are in flight. Gen III+ and Gen IV reactor owners, OEMs, EPCs, specialty fabricators and contractors, federal agencies, state regulators, and Wall Street need to learn fast from the eras that brought the industry to today and recognize that "one more chance" is not guaranteed to the nuclear sector.

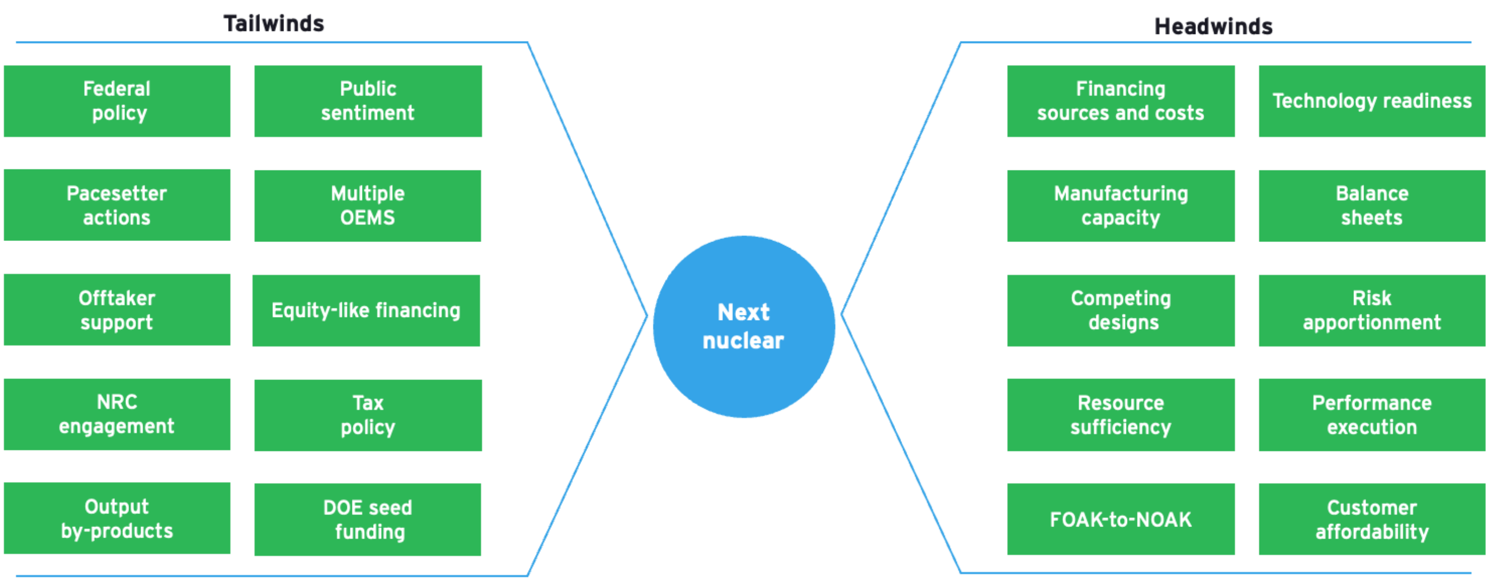
The Gen III+ and Gen IV challenge

As the nuclear industry approaches the next generation of reactor technologies, the major OEMs are wrestling with their future. Will it be big box Gen III+ units, SMRs, micro-reactors, revolutionary Gen IV+ reactors, adopting fusion technology, or some mix in the next nuclear portfolio? In 2025, the nuclear industry finds itself buffeted by tailwinds and headwinds that can affect its momentum and outcomes. Tailwinds such as positive public sentiment, federal startup funding and in-flight NRC licensing applications point to the promise of an actual next nuclear evolution.

However, multiple headwinds counter this enthusiasm and point to the difficulties in attaining and sustaining meaningful development progress. These headwinds include the absence of large-scale federal funding for big box plants; sufficient US manufacturing, construction and technical capacity; and still-to-be-implemented learnings from prior Gen III+ projects that could reduce significant cost overruns and schedule delays. (See Figure 5)

Figure 5: Nuclear tailwinds and headwinds

Factors affecting Gen III+ and Gen IV



FOAK = First of a kind
NOAK = Next of a kind

These factors affect whether, how and how fast any next nuclear renaissance can begin and sustain progress. As the nuclear industry formulates its plans to rejuvenate big box or initiate SMR plant design, development, construction and startup of the next fleet of reactors, it will need to undertake a thoughtful and rigorous review of the impediments to success, as well as the requirements to achieve a more positive outcome than prior eras for big box plants, and now SMRs, whichever technology is being pursued.

Whichever technology prevails, the same conundrum exists as in the recent Gen III+ period regarding funding, domestic tooling and fabrication infrastructure, and insufficient know-how. This places developers, owners, OEMs, EPCs and specialty fabricators and contractors behind the curve on general preparedness, never mind detailed project planning, contracting, training or readiness.

The industry experience gap is large, and solving it will necessitate an industry-wide commitment to define, create, stand up and leverage the breadth and depth of required infrastructure, e.g., resources, fabrication plants, forging capabilities, supply chain system and training capabilities. If executed well, future projects can be expeditiously and effectively conducted and project participants will be ready to undertake the critical elements of next nuclear development and construction.

But the inability to overcome sector shortcomings increases the risks that current planning assumptions are unattainable. If sufficient prework is not conducted and completed, high uncertainty over already soft estimates will continue, planned results will become even more difficult to produce and the necessary infrastructure for execution will not be available to support simultaneous plant construction. To achieve a palatable delivered price and targeted schedule duration close to public estimates, critical planning, readiness and execution gaps need to be fully addressed. This requires attention to the most impactful assumptions and the likelihood of realization — a realistic view of FOAK costs and schedule.

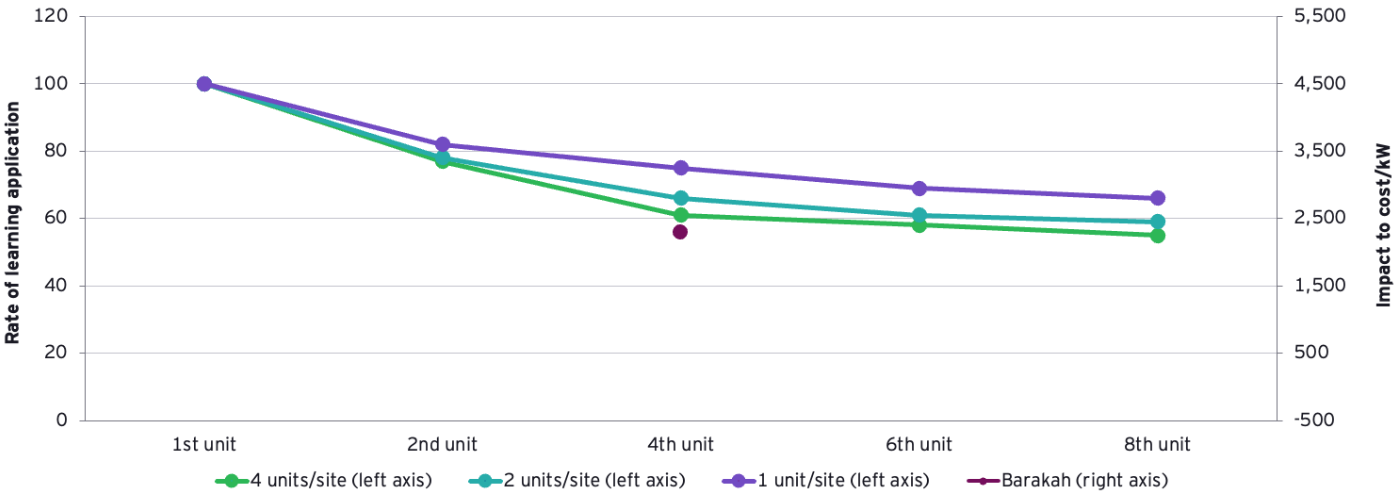
Prior global big box FOAK estimates in the early 2000s ranged from $1,200/kW to $7,400/kW and turned out to be several multiples of the original estimates for those plants when finally completed. The big box, four-unit, international plant was substantially cheaper due to a steady learning rate across construction in these multiple units. In addition, it was helped by common plant design and attention to project management that future AP1000 owners, in particular, can hope to emulate.[7]

Estimates for new, single plant, US big box development and construction vary from $6,154/kW to $7,349/kW from composite estimates to $6,000/kW to $10,000/kW from recent U.S. Department of Energy (DOE) views, with NOAK ranging from $3,600/kW to $6,200/kW.[8,9] But these prior estimates were not based on higher interest rates or commodity material prices offered in the market today. And estimates of the levelized cost of electricity (LCOE) can range from $66/MWh to $77/MWh to $141/MWh to $221/MWh.[10,11]

While only a handful of recent big box plants have been completed, the expectation for and necessity of these scale plants, as well as SMRs is high, reflecting steep learning curves as more units are completed. (See Figure 6)

Figure 6: Gen III+ learning curves

Conceptual plants and Barakah



Source: Financing New Nuclear in Sweden, EY, March 2024, [1]Reduction of Capital Costs of Nuclear Power Plants, Nuclear Energy Agency (NEA), 2000, [2]The Potential for Nuclear Cost Reduction, Gogan 2019

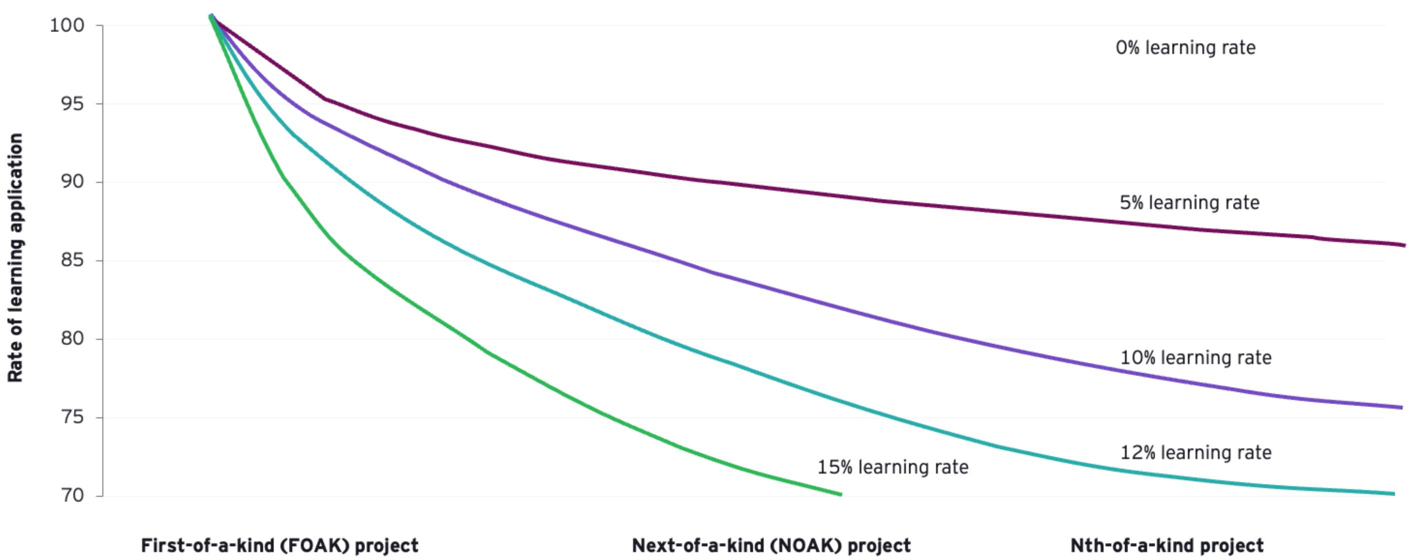
Much can be learned from the U.S. Navy Virginia-Class submarine program, which experienced the adverse impact of initial FOAK designs and construction techniques, including high project costs and longer durations. Later, the Navy program benefited from a fundamental reconfiguration of how boats were constructed and produced. Repeatable improvements had a positive, cascading effect on succeeding costs of construction.

Looking at similar FOAK-to-NOAK outcomes, the Idaho National Laboratory within the DOE observed learning rates of between 5% and 15% (performance improvement curves) for each succeeding project of a similar type as the learning curve was incorporated, until NOAK was achieved.[12]

Similarly, prior OEM FOAK estimates for SMRs provide a wide range of potential overnight capital costs from $5,000/kW to $9,120/kW.[13] Without contemporary US experience, these estimates are highly preliminary. If the industry can develop fleet-scale, multiunit development-and-construction experience, and related planning and execution learnings, then OEM estimates of future NOAK costs could range between $2,805/kW to $6,191/kW, based on composite estimates, to $2,250/kW to $4,100/kW, according to OEMs and industry releases.[13,14] LCOE estimates are even foggier for SMRs, with ranges between $40/MWh and $90/MWh.[15]

Figure 7: Learning rates on big box construction costs

Estimated rate curves



Source: Financing New Nuclear in Sweden, EY, March 2024

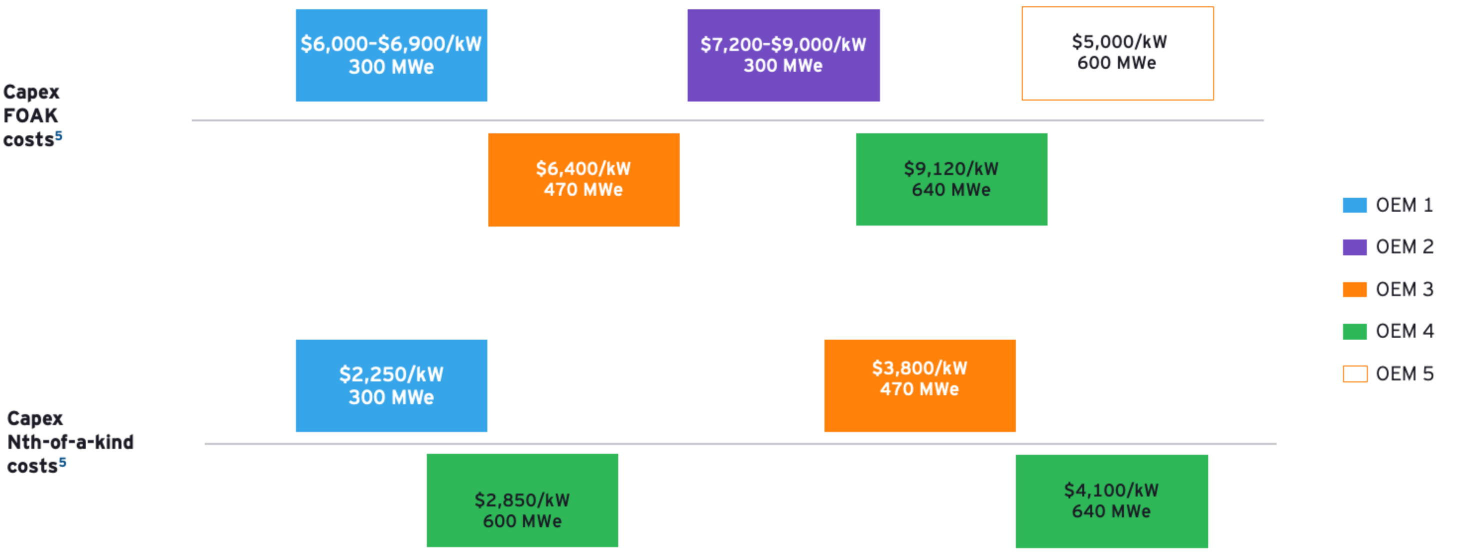
But even front-end challenges to pre-project planning and execution will only provide a few data points until more plants are completed under a consistent regulatory approval model and the learning curve is incorporated into succeeding projects.

The nuclear sector must confront this challenge as it seeks to build economic fleets of new nuclear plants and embrace the mandate to accelerate and embed learning curve outcomes to enable sustained economies of scope (design) and scale (volume). The economies nuclear plant owners seek will only materialize if dramatic performance outcomes are delivered at scale by thinking about delivering a growing fleet, not just one plant at a time. (See Figure 7)

The move from FOAK to NOAK for first-generation SMRs should rigorously and quickly incorporate learnings for the nuclear island, turbine building, auxiliary buildings and balance of plant. Learnings will need to be defined at a much lower level, e.g., design, fabrication, assembly, installation and construction of internal reactor systems and equipment, for this prior experience to be valuable.

The industry tends to think of the full unit of development and construction, the plant. But SMRs are simpler projects than big box plants with three primary elements: the reactor (modules, internals and supporting systems), auxiliary buildings and the balance of plant. Each of these elements provide an opportunity to pursue learning curve effects in different ways. To accelerate the incorporation of learnings as rapidly as is practical, owners, OEMs, EPCs and specialty contractors need to rescale their thinking to individual reactors and modules, not just the full reactor containment or plant as a whole. The entire industry needs to change how it thinks about pursuing and delivering economies, i.e., where they exist. (See Figure 8)

Figure 8: Estimated SMR plant costs
OEM estimates



Sources: Company websites; Nuclear Regulatory Commission; U.S. Department of Energy; investor presentations; various press stories, EY-Parthenon analysis
SMRs = small nuclear reactors

Relevant OEMs would like to think capital expenditure estimates represent the worst case. However, estimates are predicated on US COD dates extending into the early 2030s, and it would not be surprising if cost estimates are highly understated. The cost risks include elevated interest rates, delays in licensing or design approval, commodity price volatility, supply chain constraints, EPC contracting challenges, performance failures, or schedules extensions due to tear-out and rework.

Estimates with this much (or higher) variability already concern owners, investors, regulators and skeptics about the viability of nuclear power. Unfortunately for megaprojects with new nuclear power technology, the sector will not have a solid benchmark for performance until the first plant achieves COD, and maybe not even then due to preexisting development and construction conditions.

For the industry to finally deliver on the promise of affordable nuclear energy, it needs to rethink how it plans and constructs these plants and stress-test all assumptions, roles, structures, techniques and risks to identify where current assumptions can be challenged and how the delivery model can be improved.

This means confirming FOAK estimates fully incorporate concepts on standardization, simplification and optimization in original design. It also requires breaking down learnings by discrete elements that allow owners, OEMs, EPCs and specialty contractors to focus on controllable activities that matter to plant production and construction, startup and turnover, e.g., front-end concepts on mass production, site optimization, building and equipment modularity, and fabricator, OEM, supplier, contractor and owner experience across plant development, design, production, construction, quality assurance and project management, project controls, and risk management activities.

Owners and other parties need to recognize that learnings come from actual experience, and the more repetitions, the better the insights obtained. Hence, unit-to-unit and reactor-to-reactor performance will likely lead to accumulated and expanded learnings as this experience is embedded in succeeding units through a production series model.

The path to NOAK

The path to long-term next nuclear success will be sustainable when early FOAK results turn into perpetual NOAK outcomes. And this can only occur if owners recognize where and how to purposefully, aggressively and imaginatively tackle the fundamental levers that can drive performance, productivity, speed and quality into lower costs and a shorter schedule. Owners can accelerate their ability to realize significant economies of scope and scale, by following an eight-point plan.

- **Risk analytics:** adoption of comprehensive and integrated risk identification, evaluation and mitigation techniques intended to provide early risk assessment and enable owners, OEMs, EPCs and specialty contractors to prepare for occurrences, impacts and risk apportionment
- **Mass production:** scaling of fabrication facilities, collocation of facilities within plant hubs, prefabrication of high-use forms and core equipment, and adoption of advanced manufacturing, automation, digital and AI techniques
- **Multi-module siting:** development of a clustering vs. island model with multiple regional sites to create single, natural hubs for multiple plants to enable integration of development, design and construction capabilities to drive sustained production and deliver cost excellence
- **Fabricator learning:** applied focus on identifying, replicating, building in and stress-testing real-time experience to develop learnings related to machining, design features, technology deployment, transportation and project interfaces
- **Supplier excellence:** readiness of suppliers for execution with stand-up of nuclear and discipline training academies as part of each regional hub, developing a modified incentive contract model, and adopting a rigorous supplier surveillance model and inspection program
- **Contractor learning:** programmatic focus on identifying, replicating, embedding and stress-testing real-time experience, to develop work package planning and execution, system interfaces, risk discipline, turnover coordination, and earned value improvement learnings
- **Real-time quality assurance:** rigorous philosophy redefinition and pre-work QA program establishment, including roles, interfaces, processes and procedures, related to design parameters, installation conformity, construction walk-downs, system turnover, and as-built design close-out
- **Owner learning:** program-level focus on identifying, replicating, embedding, and stress-testing real-time experience, to develop governance, project management, partner collaboration, quality assurance, risk management and knowledge sharing learning

Framing of pursuit of NOAK outcomes should be formally incorporated into owner planning in parallel with consideration of the development of FOAK cost and schedule estimates. While developing a well-conceived plan for project execution at each individual plant and unit is table stakes, the mindset of thinking about "what's next" can be a valuable addition to owner processes so constant focus on improvement and learnings is formalized into contemporaneous execution, rather than after-the-fact compilation.

But the focus on application of learnings to future efforts will mean little if the industry does not cure a more fundamental issue: inadequate attention to potential project risks. Review of prior project outcomes makes it clear that results are highly linked to the level of rigor expended in risk identification, assessment, analysis, quantification, mitigation and continuous monitoring for potential new risks. In too many prior projects, quality risk analysis was underappreciated and underperformed by owners, making it hard to avoid the adverse outcomes that followed.

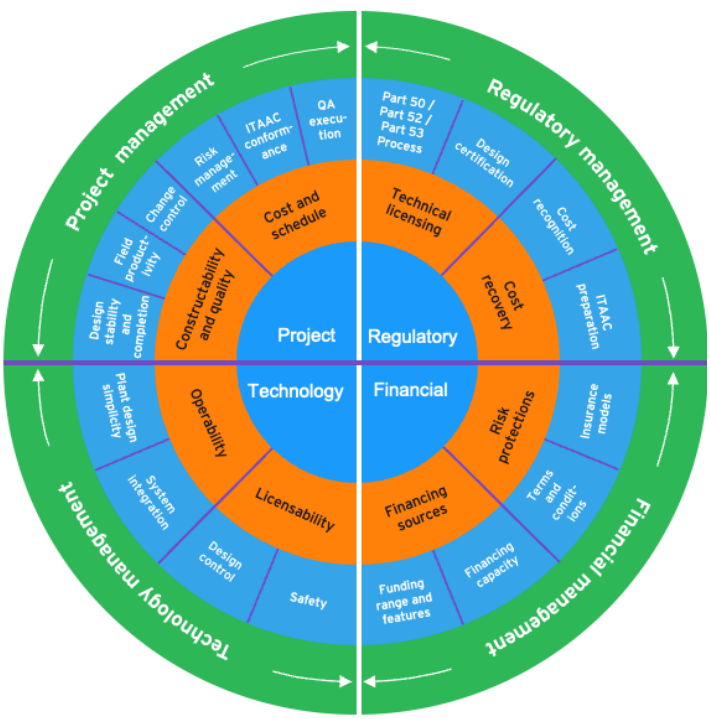
Analysis and management of risk is a particularly critical process to embed across a nuclear program or fleet. In earlier Gen II, Gen III and Gen III+ projects, US nuclear owners (and their OEMs and EPCs) did not consider this planning and execution focus to be an important dimension of project governance. Owners considered themselves protected by their fixed-price contracts, project management processes, regulatory recovery models or confidence in their capabilities. But contracts are not a substitute for deep risk identification, assessment and mitigation planning as OEMs and EPCs are not inclined to absorb risk for FOAK plants.

Risks to be evaluated typically span the financial, regulatory, technology and project areas, and analysis needs to be initiated well prior to potential project execution. Owners, OEMs, EPCs and specialty contractors all need to be risk-focused and collaboratively engaged through the entirety of the pre-development, production, construction and delivery stages, and stress-testing needs to be continuous rather than episodic.

Prior project misjudgments from early project execution affected concurrent and completed cost outcomes. For future projects, risk analysis and management need far more attention for big box plants, SMRs and micro-reactors. (See Figure 9)

Figure 9: Legacy and current risks

Project risk analysis



Source: EY-Parthenon analysis

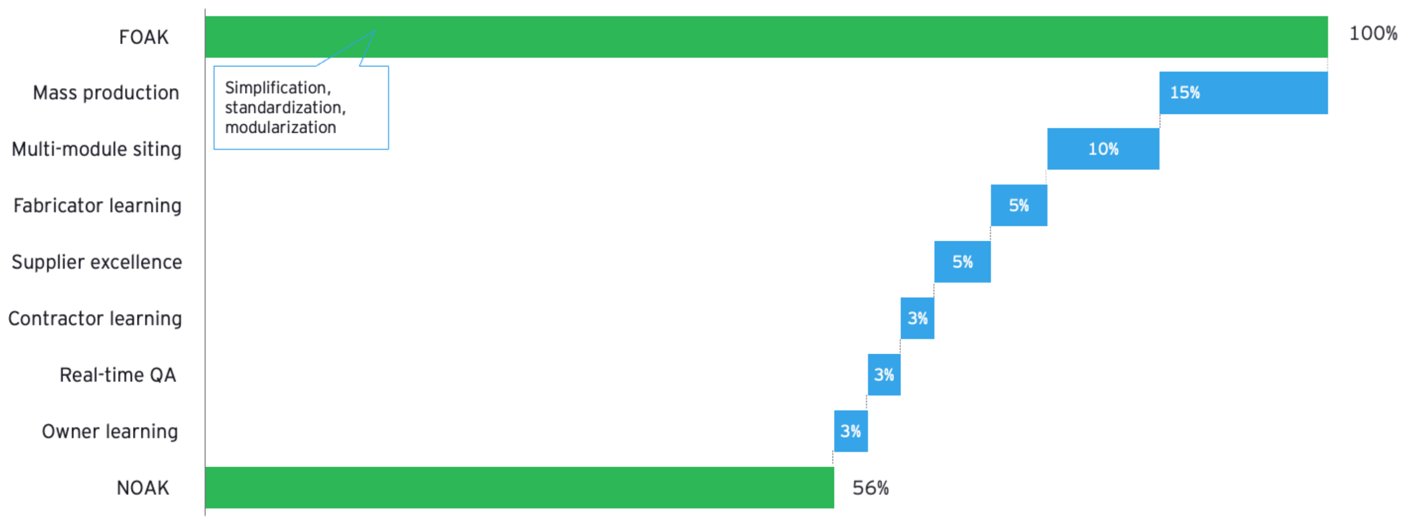
Effective up-front risk assessment, analysis, management and mitigation are necessary capabilities all parties need to grow and mature, as the precursor to project controls, and the underpinning of project management. From the owner board of directors to a project oversight board, high visibility and importance need to be placed on managing risk associated with project controls, project management and project turnover. For next nuclear projects, the effectiveness of this process may determine if a successful and affordable outcome is realized.

For some OEMs, multiple projects will be pursued across different sites, e.g., Canada, US, Europe, with each project moving in parallel but not always in tandem. This model allows for a learning curve to occur at two project levels. The first level is critical equipment fabrication, modular installation and system integration. The second project level encompasses site facilities, e.g., turbine, radioactive waste, fuel storage, cooling towers and switchyard facilities. Each of these elements have distinct complexity, modularity and sequencing, which lead to unique opportunities to rapidly transfer learning curve effects from a couple of plants to a standard fleet wherever it is. (See Figure 10)

Other industries, including the defense sector, have captured lessons and the nuclear sector can do that as well. But the nuclear industry needs to aggressively make moving from FOAK to NOAK its North Star and place this achievement at the center of its planning model. The focus needs to be on readying the next nuclear fleet, not just the next plant. The key principle underlying moving from FOAK to NOAK: imagine the end state, then chart the path to get there.

Figure 10: Bringing NOAK costs to fruition

Capital investment cost reduction potential, %



Source: OECD, Idaho National Laboratory, EY-Parthenon analysis

Owners need to think about driving megaproject lessons learned elsewhere into the first SMR built and extrapolating them across each one that is built. Instead of taking a multiyear, end-state view of plant COD, adopt a reactor module-to-reactor module and balance-of-plant emphasis where immediate gains can be integrated into multiple plants as experience grows.

Several foundational requirements are imperative to achieving the desired NOAK results:

- A standard plant design is sacrosanct, at least within a single host country. While regulatory standards and plant sites can differ across countries, many countries look to the NRC as the gold standard. Efforts should be made to eliminate unique design standards.
- Plant design needs to be complete and consistent with the Standard Design Approval (SDA) issued by the NRC. This is a critical requirement, so construction work packages are issued once and do not lead to construction rework.
- Accelerated training is needed for owner project management, OEMs, EPC, specialty fabricators and contractors, indirect and craft labor, and quality assurance providers. This is a fundamental element of project readiness and reduces staffing churn and recurring costs and improves delivery quality.
- Stand up a capable, prepared and integrated supply chain system to avoid unnecessary costs and enable sustained productivity. This alone will allow the owner, OEM and EPC to focus on production rather than remediation, and avoid schedule slippage from materials and equipment delays and third-party performance.

The unfavorable results of many Gen II, Gen III and Gen III+ projects were partially the result of several significant and uncontrollable exogenous factors, as well as numerous self-inflicted actions that could have been averted during project execution. But more importantly in the context of Gen III+ plant results, and a precursor to additional acts of commission, were the acts of omission, e.g., the failure to undertake adequate risk analysis, which could have identified where potential shortcomings could be anticipated and mitigated. To mitigate the inherent risks associated with Gen III+ and Gen IV next nuclear projects, a full suite of risk identification, assessment, planning, mitigation and apportionment actions among the broad spectrum of stakeholders is essential.

Apportioning risks across future nuclear projects doesn't mean just enhancing where to recognize and evaluate planning and execution risks, but to create a collaboration-based model for how to align the long-term interests of all the players involved with nuclear development and delivery across a single plant location, as well as across a multiplant "hub" as a means of dramatically reducing risks.

To truly impact next nuclear project risk levels, future developers and owners can consider adopting a full integrated delivery model that designs and stands up a fully cohesive and collaborative way to organize and execute across multiple participants; developers, owners, partners, OEMs, EPCs, specialty fabricators and contractors, fuel suppliers, power off-takers (chemical processors, oil and gas producers, hydrogen blenders), and financiers.

The industry needs to recognize speed is not always a virtue, and readiness is the building block to drive desired outcomes. The areas above are predicates for readiness and are necessary components of a well-thought-out plan for enabling, expediting and accelerating work initiation and execution. But these items will not determine whether NOAK has a chance at attainment within a reasonable time.

The greatest impacts on controlling and reducing the cost of plant delivery relate to taking advantage of economies of fleet construction, i.e., adopting relentless up-front planning, standardization and simplification, building an integrated infrastructure footprint, driving a culture of continuous improvement and excellence in execution, incentivizing vendor and contractor performance, bridging the gap between quality assurance oversight and real-time construction, and incorporating lessons learned into real-time transfer and carry-forward from plant to plant, or reactor to reactor.

The rate of project learnings will not be uniform over time and may be either steep in the beginning or gradual over time depending on the nature and complexity of an undertaking. For example, learnings that relate to fabrication facility configuration cannot occur immediately, multi-entity execution integration will grow over time, while third-party work execution learnings can be adopted immediately. Together, all of these can combine to produce a 40% to 50% reduction in execution costs to delivered plant outcome, which is what is needed to put the levelized cost of electricityt into the right comparative territory, according to EY-Parthenon analysis of available estimates.[16]

The next nuclear paradigm

The new paradigm for nuclear development needs to address four key decision and planning challenges: technology uncertainty, divergent learning curves, supply chain adequacy and regulatory risk. Combined, these create a Gordian knot that prevents appropriate risk apportionment across the range of involved stakeholders.

The primary selection required of new project developers is plant type and technology. While legacy plants have been designed with big box reactors larger than 1,000 MWs, new SMRs and micro-reactors at 300 MWs and less than 20 MWs, respectively, offer an alternative of modular design and development of multiple units that promise cost reductions as the installed scale increases.

Further, alternative coolants such as molten salts and liquid metals (e.g., sodium, lead) are being explored for their safety and efficiency benefits. These coolants enable reactors to operate at higher temperatures and lower pressures, potentially reducing the amount of fuel required and making waste easier to manage. Despite these advancements, the ultimate goal remains fusion energy, which, although highly promising, may still be at least a decade or more from commercial viability.

The development cycles and learning curves for SMRs and traditional large nuclear plants differ significantly. Large nuclear plants have established, but multiyear, learning curves, due to their bespoke construction processes and regulatory complexities. In contrast, new Gen III+ large nuclear plants and SMRs are designed for modular production, promising rapid cost reduction through significant factory manufacturing, hub-based localized integration and continuous production learning; once one gets built to provide a model plant.

Some planned SMR designs are more expensive than big box plants on a kW basis. Applying modularization, advanced manufacturing technologies, and increasing scale is expected to achieve cost reductions of roughly 50% to more than 60% between FOAK and NOAK plants, potentially conferring SMR cost advantages over big box plants in the long run.[17]

Thus, a developer may choose a big box plant at today's cost, but risks ending up with an uncompetitive asset should SMRs create a fleet effect faster than larger plants during the life of the plant. Conversely, choosing SMR today accepts the risk of uncertain, but high, FOAK costs for SMRs, with their economic competitiveness unproven at large scales.

Ideally, the developers of the nuclear plants — whether big box or SMRs — would leverage a liquid, competitive supply chain that would efficiently provide equipment and services required to develop a growing portfolio of nuclear plants, regardless of scale or location. However, the erratic experience and slow pace of recent nuclear plant development has led to deterioration in the nuclear supply chain. Sporadic demand and long lead times have caused financial instability among suppliers, leading to bankruptcies and overwhelming disruptions.

The modular SMR approach aims to mitigate cost issues by enabling more localized and scalable manufacturing that does not exist today. Otherwise, developers and owners must rely on either a supply chain where sellers are in part, or wholly owned by the reactor vendor, or a supply chain model where suppliers have a long-term strategic relationship with the reactor vendor. Ideally stronger forms of supply chain integration would be used in early days of scaling and a competitive and liquid supply chain would emerge in the long run, but the initial cost of security will remain.

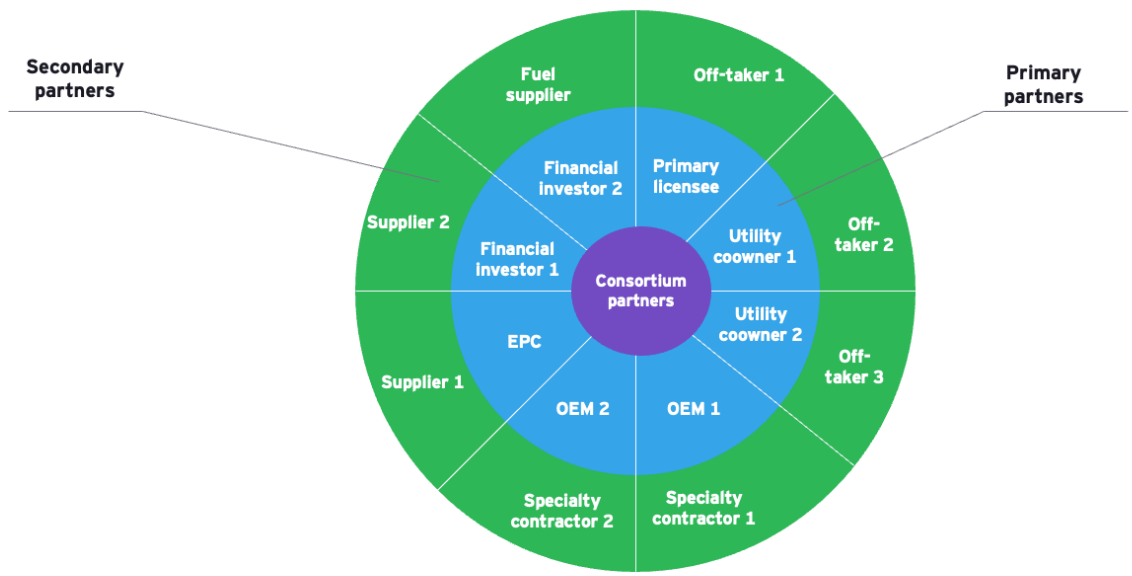
Each new reactor design, licensing application and site selection requires approval from the NRC (or other international governmental authority), which can vary in requirements and timelines. Design changes would trigger new approvals, further increasing timelines and adding to risk of delivery. Regulatory risk is significant and can inflate costs. Obtaining a design certification for an SMR can take multiple years, tens of millions in NRC fees and several hundred million dollars of in-house costs.[18] Efforts to streamline regulatory processes, such as the NRC's proposed Part 53 framework, aim to reduce these costs and risks for new types of reactors. However, the risk of design changes and the doom-loop of regulatory approvals is still on the shoulders of developers and owners, therefore reinforcing the importance of choice of technology and quality of the supply chain.

With the cost of a stand-alone SMR or big box nuclear plant cost prohibitive for a single private owner, a consortium model offers an innovative opportunity where multiple entities with common interests create an aligned ownership, governance, management, delivery and operating framework.

Rather than think about next nuclear projects as individual plants, the need to shed and share risk leverages a portfolio effect of developing and building multiple plants and spreading resources, costs, outputs, power supply and financing. (See Figure 11)

Figure 11: Framing a consortium model

Potential range of consortia partners



Source: EY-Parthenon analysis.

The consortium model is new to the US utility industry, but not to other industries that pursue megaprojects, where the pooling of purpose, roles and resources is commonplace. A good example was the multi-owner project ownership model used by large oil and gas exploration and production companies related to the Trans-Alaska Pipeline System (TAPS), which was constructed to move oil from Prudhoe Bay to Valdez, Alaska. Similar oil and gas project models were undertaken in the North Sea and elsewhere around the globe with public and private investors.

The TAPS consortium was structured as a joint venture (JV), with each company dedicating financing, working capital, executive leadership, functional project resources, equipment and operating personnel coincident with their ownership stake. The JV was necessary to develop and construct TAPS due to its high costs ($8b) in 1977 dollars and nearly decade-long duration.[19]

This project led to other owner JV projects, in other parts of the North Slope area, enabled by the initial efforts and experience developed across multiple oil fields. As the scope of production and transport expanded, the original owners reshaped their ownership stakes with existing members and new participants.

Highly technical projects, such as the United Launch Alliance in space rocket development, similarly involve multiple parties to create a collaborative and integrated financing, project management, design, fabrication, assembly, test and mission support model to focus on extraordinary projects. This alliance harnesses the capabilities of both federal government agencies and other large-scale public aerospace.

For the next nuclear era, the initial objective of a consortium is to accomplish a principal outcome of improved economies for the first SMR or next big box plant constructed, economies that arise from: full site presence of each participant for fabrication facilities, module assembly, reactor and balance of plant design engineering, unit construction, supply chain testing, project management headquarters and quality management.

The obvious intent of this model is to leverage location, partner proximity, common design, facility specialization, and management visibility to create a permanent nuclear ecosystem on a subregional basis, wherever next nuclear owners choose to build out a cluster of plants vs. an individual island. These could comprise both SMRs and big box plants. This ecosystem provides an evergreen hub that is self-perpetuating and grows as the plant mix evolves and site footprint expands.

But a long-term aspiration should be that consortia create hubs that can plan and execute multiple plants simultaneously, i.e., a single site that works across multiple owners to build a portfolio of similar plants that will accelerate and simplify the drive from FOAK to NOAK. Several options can exist for how to structure a consortium, e.g., unique plant ownership, full sharing of all partners and facilities, common fleet ownership across sponsors, or a blend of ownership or participation models depending on the scale and timing of plant development and construction.

Designing an ecosystem

The nuclear industry acknowledges that creative thinking and solutions to planning and execution issues of past eras will form the rubric for the "next nuclear" model. Innovative solutions are easy to point to as the necessary savior for the sector, but a technical, process and management focus does not, by itself, form the foundation for future success. Rather, the solution needs to be much more inventive, inclusive and permanent. Evolving from FOAK to NOAK outcomes demands a more imaginative approach to how next nuclear gets built, with a singularly distinct archetype for collaboration, coordination and collocation; an integrated ecosystem.

Future nuclear development needs to advance beyond the company-by-company approach to plant development, production, delivery and operations. It needs to move to a more tightly designed framework that links multiple owner, plant and partner objectives with site-specific installation, sequence and startup maturity to create a portfolio effect.

What needs to be conceived, built out and operationalized is a much more imaginative, inventive, inclusive and permanent solution: an integrated site-based ecosystem that focuses on advancing the ability to stand up, expand and maintain a unique model for repetitive next nuclear plant and support facility construction, alignment and integration. This model establishes a singularly distinct archetype for collocation, collaboration and coordination.

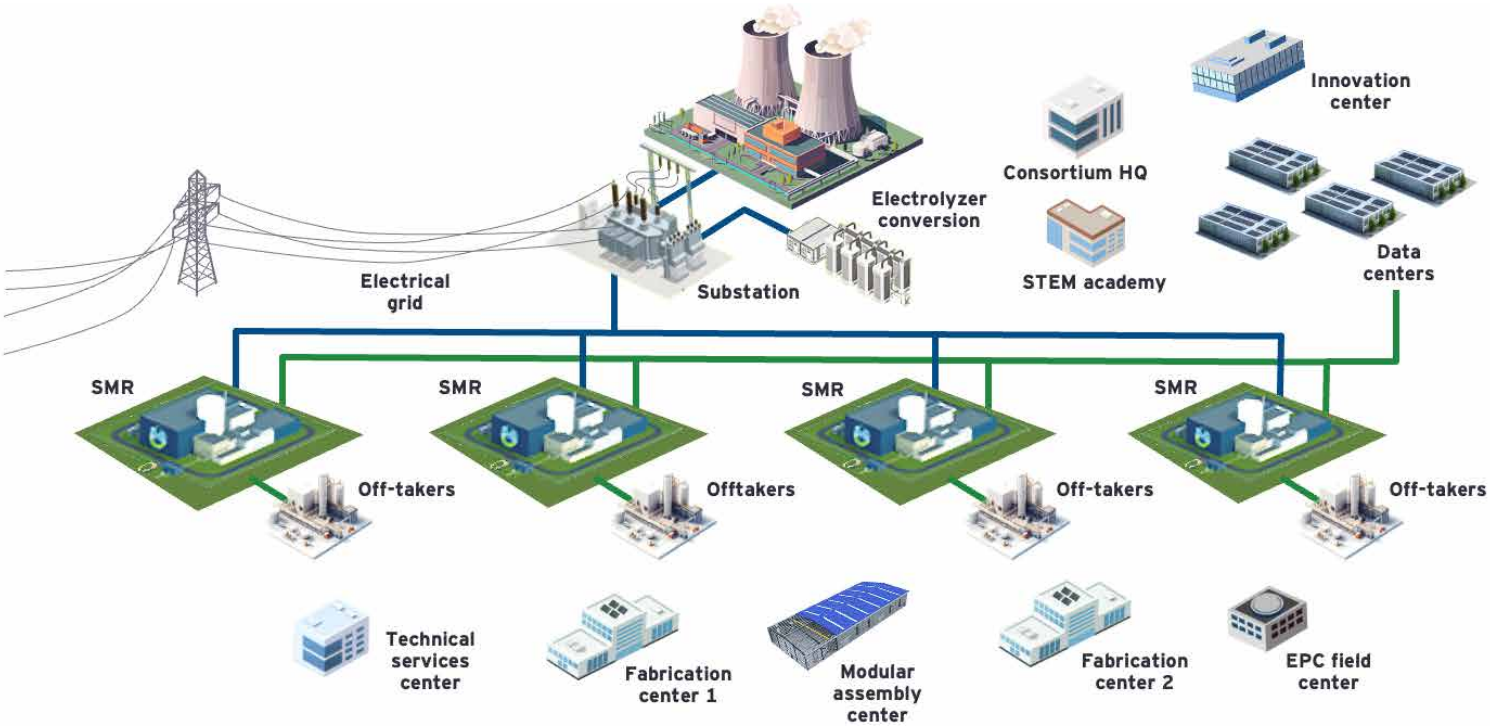
At the center of this model is an underlying premise that establishing a prototype for future nuclear development and operations, serving one or several owners, is a superior approach to lower plant costs, speed up COD completion, raise product quality and sustain economies of scope and scale. This premise is based on the expectation that collective partners or a sponsored ecosystem can improve performance from the first plant and build performance through each successive unit, whether micro-reactor, SMR or big box.

An ecosystem can be imagined using an existing site as an illustration: multiple nuclear units and multiple buildings would already exist at the plant, along with other ancillary facilities, such as switchyards, rail lines, warehouses, lay-down areas, piping shops, labs, training facilities and administration at the core of the site. The potential for highly efficient clean energy,

future by-product facilities, such as electrolyzers for hydrogen and desalination, as well as other power supply platforms, such as renewables or storage, can also be added to enhance the value of the ecosystem.

The core element of a generation hub is the creation of an anchor for the ecosystem that will support future build-out of land, roads, water, facilities and spent fuel storage, as well as additional plants, on-site fabrication, assembly centers, technical support buildings, innovation centers and multi-owner headquarters buildings, as appropriate. The scale and expandability of an ecosystem are only limited by the amount of available footprint (developable acreage, scope of ancillary facilities, e.g., data centers, access and egress availability, water sources and natural barriers), the impact of greater scale and concentration on transmission and system loads, and the imagination of owners and partners. (See Figure 12)

Figure 12: Building the nuclear ecosystem
Integrated partner site



Source: EY-Parthenon analysis.

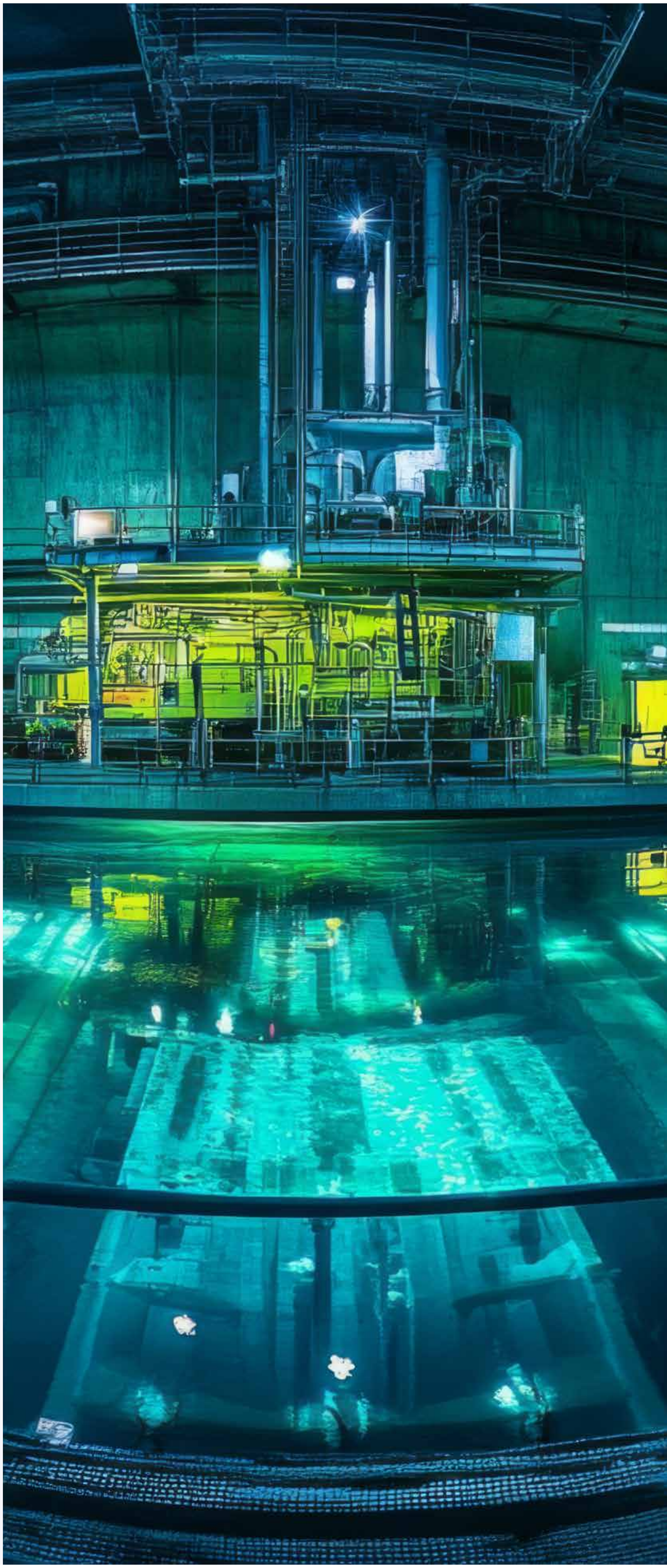
An existing nuclear plant site could enable micro-reactors, to expand to match load, or SMRs to large-scale baseload reactors to provide a mix of current, near-term and long-term load. This is not the typical mission of a nuclear plant owner-operator, but when suitable sites are available to enable nuclear fleet expansion with economies of scale, a formal ecosystem offers an attractive proposition.

Besides providing the ability to align power supply across several load profiles, the ecosystem footprint offers the opportunity to pursue scalability and optimization goals, as well as embed a portfolio model for a multifaceted nuclear generation fleet and an integrated platform to achieve critical mass across owners and the full range of partners in as integrated, collaborative, quality and economic manner as possible. For any other suitable location, the fundamental underpinnings are unchanged: bringing the principal owners and partners together to a common site to drive the build-out of multiple plants and other facilities, and doing so in a manner that is as smart, integrated, collaborative, high-quality and as economic as possible.

In an integrated ecosystem, a common project governance and management structure is utilized to simplify owner and partner collaboration, communication, interfaces and decision-making. This model is enabled by the previously described consortium approach where partners are engaged as a group to focus on whole-of-plant outcomes and can be extended or refined to address downstream products, such as hydrogen, ammonia, methanol, etc., for clean fuels.

An ecosystem can be structured to enable all owners and some partners to share project-related financial outcomes from integrated project delivery, inherent economies of scope and production of energy by-products. It also allows the consortium partners to levelize the benefits of a dynamic, end-state portfolio, i.e., spread the benefits of plant learnings across the founding partners over time, so first-in owners do not subsidize last-in participants, and all partners perpetually enjoy the benefits of economies of scale.

An ecosystem-based project production and delivery value model, efficient cost performance, effective schedule management and quality project execution are all direct benefits to the most involved parties on the site to produce lower delivered costs, greater economies of scale and scope, faster plant completion, higher-quality construction, expanded site facilities and reduced cost of capital.



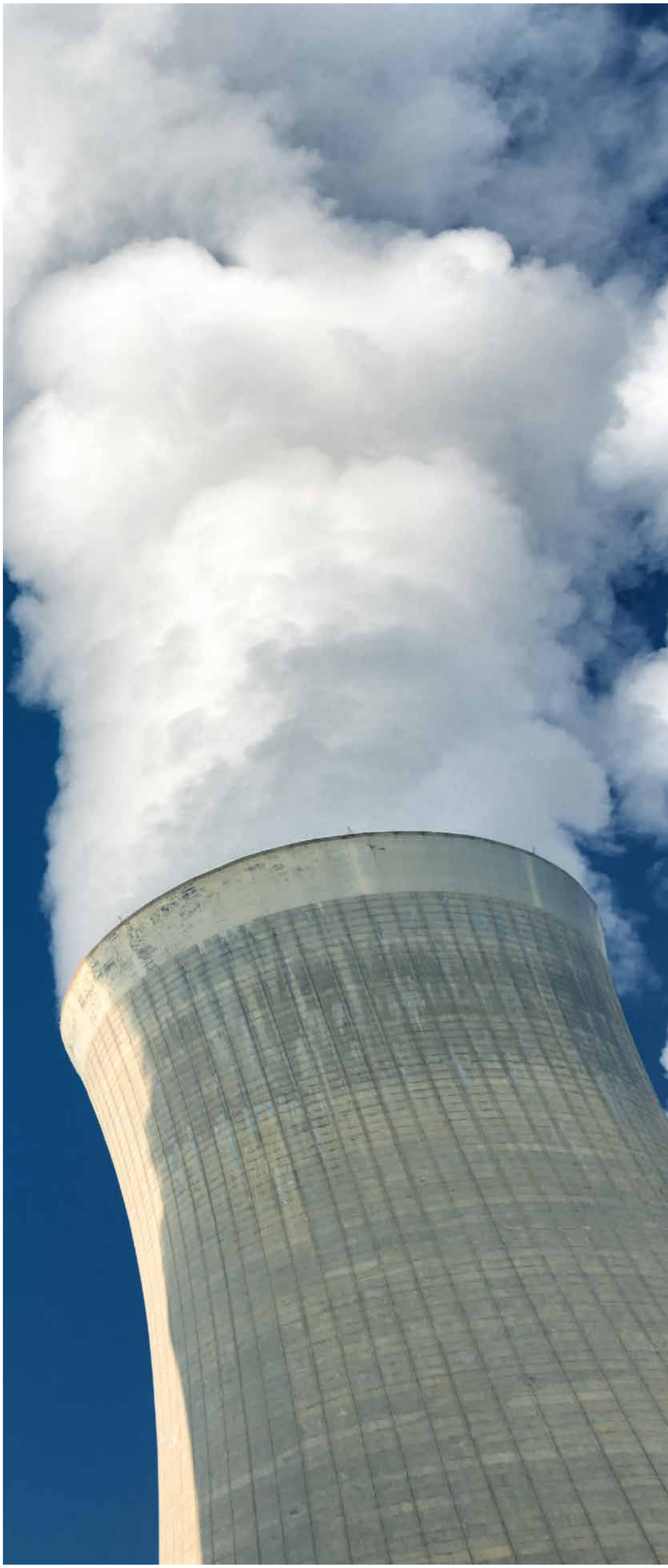
Adopting an ecosystem model does not only apply to partner alignment, collaboration and execution to produce desired delivery outcomes; it can also be beneficial to a broader set of stakeholders external to the project who can also share in different sources of value enabled through a robust "hub" concept.

An ecosystem-based project production and delivery value model employed by the owner(s), OEMs, EPCs, specialty contractors and offtakers focuses on productive resource application, integrated decision-making, collective risk management, efficient cost performance, effective schedule management and quality project execution; all direct benefits to the most involved parties on the site and should produce lower delivered costs, higher economies of scale and scope, faster plant completion, higher quality construction, expanded site facilities, tax benefit capture, and reduced cost of capital.

But potential beneficiaries also include local communities, legislatures and regulators that can benefit from new permanent jobs, a stronger tax base, increased municipal vitality, expanded local spending and lower financial risk. These benefits also support incremental investment opportunities, broadened economic development potential and increased funding for local projects, all of which can heavily influence new nuclear development.

As utility nuclear plant owners improve outcome likelihood and value through adoption of an ecosystem model, they also gain incremental value beyond successful project delivery. The project owners can reinforce a positive local presence and reputation as an attractive partner with its broad stakeholder base. IRPs filed with state regulators can demonstrate sustainable local value that inure to stakeholders directly from a project.

The ecosystem model signifies nuclear commitment, accelerates scale economies, simplifies plant production and delivery and localizes capabilities to support the speed of execution and quality of execution. Since participants in the "ecosystem" would likely exhibit different business, management and engagement models, risk tolerances, and time horizons, and enhanced risk management will complement and enable ecosystem configuration and integration.



Financing nuclear's future

For many current vintage nuclear projects, capital needs exceed the financial and risk capacity of interested single private company participants. Simply put: financing solutions are lagging demand for nuclear power.

Without a clearer roadmap to sufficient future nuclear financing concepts and models, the inadequate level of funding necessary to support plant development and construction may impede ambitious plans for nuclear plant delivery. Consequently, nuclear projects are focused on identifying and obtaining some incremental type and amount of government support to mitigate high costs and the risk of overruns and schedule slippage, such as loan guarantees.

But the nature and level of financing needs to consider and fit the conditions of the country. For example, energy market design defines the framework for how to maximize system output and value, i.e., enabling sufficient transparency and benefits to participants. Partner and customer risk tolerances establish whether and how costs can be shared with consortia members and offtakers, i.e., how an owner can define a targeted and tailored risk apportionment and cost-sharing mechanisms. Regulatory schemes establish frameworks for licensing speed, performance incentives or other tariff designs to drive desired outcomes.

These elements are all foundational drivers for achieving bankability of future projects and are the basis for access to sufficient financing in the current skeptical financial market environment. Having an early financing model in place signals to financial, market, regulatory and project players that a well-conceived approach to enable plant development and construction can sufficiently fund project execution, manage related risks and capture sufficient value from a new plant to justify investment from multiple sources.

Much of the challenge to financing next nuclear lies in the more recent experience of directly involved governments and owners that had adverse project outcomes, and indirect parties, like regulators, financiers and partners, that observed these disappointing development and construction results but are yet to look past them.

The nuclear industry is recognizing that next nuclear programs are much more than commercial or financial risks and rewards. Financing is a result of the collective decisions and undertakings made upstream of a final investment decision. A recent report published by EY Sweden, Financing New Nuclear in Sweden, addresses this common challenge across countries, discusses the need for policy clarity to create a stable investment climate and compares a range of available financing options for new nuclear projects. It also breaks down investment decisions into constituent parts and identifies the conditions that enable full project financing and the requirements for effective development investment.[20]

To illustrate, the International Atomic Energy Agency (IAEA) guidelines for member states identify 19 infrastructure issues for nuclear new-build programs, including the readiness for funding and the alignment to performance milestones.[21] These infrastructure issues highlight the multifaceted approach needed to develop nuclear power plants. Though a handful of projects have progressed on technical milestones (licensing, permitting, construction and commercial operations), there is limited evidence that any project will meet its originally declared, nontechnical objectives such as cost, schedule, returns, taxpayer costs or benefits.

Consequently, the focus of public debate has shifted from the gradual realization that more nuclear is needed in the global energy mix to making nuclear projects successful. Recognizing the dynamic nature of markets and the typically long lead times needed to achieve nuclear financial agreements, a purposeful framework can efficiently organize widely available resources to create investable proposals and compress schedules. This requires that government policies and instruments, industry vision and tools, business plans, financial models, risk matrices, etc., mature in line with the technical factors, including unit costs, schedules and performance.

Among principal nuclear sector players, a dichotomy exists. Technology companies, some funded by private capital, are more tolerant of technical and commercial uncertainty, while risk-averse utilities are constrained by regulatory and financial structures. Manufacturing and services providers fall between them.

Nontraditional players like AI companies and data center operators, with emerging drivers for highly available nuclear-based power, have immediate power needs and asset lifecycles of at least 15 years, and potentially far longer. In contrast nuclear power plant owners have 10+ year development cycles with potential 80-year asset operating lifecycles. Suppliers fall in between with two- to four-year asset development timelines and 20–to–40–year asset lifecycles.

A loosening of the purse strings in the US can come with greater confidence in the industry's ability to build nuclear micro-reactors, SMRs or big box plants. This confidence can be created if the federal government, owners, OEMs, EPCs, offtakers and regulators create the right up-front policies and frameworks to provide better industry stability and enhanced financial security in advance of core planning and development cycles.

The roadmap elements to enable financing and ultimately plant delivery should be directed toward three specific models that can control the uncertainty of development, improve the preparation of planning and substantially reduce the risks of execution.

- **Developmental model:** front-end consideration to address all critical decisions — government policies, commitments and incentives; long-term program objectives, priorities and decisions; and project-and-partner planning, management and integration
- **Investment model:** contours of the financing framework and investment principles and protections — investment priorities, strategy and conditions; market attractiveness, guarantees and bankability; and financing sources, mix and types
- **Risk model:** early identification and assessment of project delivery uncertainty — risk causation, likelihood and impacts; risk ownership, apportionment and impacts; and risk management, monitoring and mitigation

In the past, attractive and valuable projects were frequently canceled when financing options were narrow, investment recovery was not transparent or guaranteed, direct subsidies or incentives were unavailable or withdrawn, and pricing methods and levels were unrealistic. Without earlier framing and specification for new nuclear that addresses these fundamental areas, other planned projects could also unnecessarily fall to the wayside.

Several prior examples exist from recent plants since 2010 that used a mix of market models and government support in various forms to address these core challenges:

- **Akkuyu, Turkey:** Rosatom's BOOT (Build, Own, Operate, Transfer) model for this estimated €18.7 b (US$20 b) project transfers the construction risk to Rosatom, with a guaranteed price for part of the delivered electricity for a period of 15 years. [22] However, financing issues have arisen due to dependency on Russian state budget funding.
- **Olkiluoto 3, Finland:** utilizing the Mankala multi-utility and customer consortia-based model and a turnkey price agreement, this US$14.0 billion project faced significant delays and cost overruns, as well as substantial tear-out and rework leading to challenging arbitration cases and financial strain on Areva as the constructor. [23]

Traditionally, government-led US programs for large-scale assets, such as nuclear, have been undersized and understaffed. Consequently, future programmatic financing set aside at the federal level needs meaningful funding, should they contemplate fleets rather than plants, and incorporate multiple levels of recipients and uses:

- **First tranche:** technology and sector development underwriting
- **Second tranche:** developer and owner capital pool
- **Third tranche:** high level of backstop funding reserve
- **Fourth tranche:** performance-based milestone funding, for new technologies

More broadly, a combination of innovative funding mechanisms is essential to avoid the pitfalls of past bailouts, subsidies and write-offs. Beyond traditional owner equity, these could include this government funding, investor equity, collaborative partnerships, pricing determinants, progress-dependent funding release and at-risk backstops that can provide continuous support and mitigate downstream financial risks from the outset. (See Figure 13)

Figure 13: Future financing model elements
Range of financing approaches

Source: EY-Parthenon analysis.

However, to make financing mechanisms attractive to government, as well as owners, OEMs, EPCs, subcontractors, offtakers, traditional financiers and nontraditional investors, future nuclear projects need to be substantially de-risked prior to detailed work execution, i.e., design initiation.

A well-funded and robust government backstop is also necessary to attract multiple stakeholders, leading to the formation of a consortium. The Mankala model in Finland exemplifies a potential consortium-based approach to nuclear project development and delivery, but this model needs reimagining to meet next nuclear financing challenges. This could involve incorporating technology developers, supply chain incubation, diverse financing sources and integrated regulatory engagement.

Within a consortium, it can be challenging to achieve the necessary level of program and project coordination, which causes delays. However, building a common vision and strategic focus among partners, having creative partnership facilitation, aligning common financial and price outcomes, and allocating dedicated funding for group performance phases can alleviate these potential issues and enable financing.

A well-functioning consortium should incorporate five key elements:

- **Appropriate convening entity:** selecting a lead entity as anchor provides not only credibility but also the prime moving impulse for the group. A convening entity could be the federal government, a leading industry player, a principal investor or an industry trade organization
- **Diverse membership:** cultivating a broad and deep mix of stakeholders, including technology developers, utilities, partners, suppliers, customers and investors, allows a manageably sized consortium to address the plethora of issues to be considered concurrently
- **Strong leadership:** attracting capable leaders for operational roles, such as program executives and project managers with experience in mega-scale infrastructure projects, helps create a coalition that is well-functioning and credible with external stakeholders
- **Clear governance:** developing oversight structures, to balance interests and establish transparent decision-making processes through effective governance models, is critical for managing the complexity of multi-stakeholder projects and facilitating accountability
- **Stakeholder management:** aligning incentives among governmental, customer, owner and technical stakeholders, including engaging local communities and regulatory bodies early in the project lifecycle, can help mitigate opposition and streamline approvals

Coalitions can be challenging to achieve the necessary level of program and project coordination, which cause delays. However, building a common vision and strategic focus among partners, having creative partnership facilitation, aligning common financial and price outcomes, and allocating dedicated funding for group performance phases can alleviate these potential issues and facilitate attainment of necessary financing from development to COD.

Reimagining the next nuclear model

Future project execution for next nuclear plants — whether micro-reactors, SMRs or big plants needs to incorporate a dramatically unique way to think about project development, production and delivery. The industry will simply not be able to rely on its prior or current philosophies, standards, approaches, processes, practices or infrastructure to meet the demands of the next generation of nuclear plants.

From top to bottom, everything about next nuclear development and construction will need to be more standard, less bespoke and consistently uniform.

Avoiding the existing challenges related to new plant economics, financing sources, technology options, owner experience, third-party staffing and infrastructure readiness, requires a thorough retooling of almost everything that the industry has relied upon in the past, whether it is a sector, project, owner, supplier or regulatory gap.

Fundamentally, owners and their OEMs, EPCs, vendors, contractors and labor unions all need to overcome the shortfalls between prior project expectations and outcomes. These cannot recur, or next nuclear aspirations will be short lived.

To evolve from building reactors to projects and multiple regional hubs, all participants and partners have to rethink a sector-wide production and delivery model, not just the project management focus of owners. The sector needs to think big, leveraging consortia and nontraditional partners and investors and think at scale to leverage the power of concentration and integration to enable seamless alignment and substantially lower unit costs.

An unexpected boost to nuclear

In the US, as the sector waits for federal government leadership, policy clarity and power supply economics to jump-start nuclear activity, unexpected players have jumped into the nuclear sector from an entirely different direction with a distinctive purpose.

Almost overnight, cloud computing hosts, hyperscalers and other companies created demand for large amounts of round-the-clock power supply, which was unforeseen by utilities. The insatiable thirst for sufficient power supply to drive advanced computing by data — particularly with the introduction of AI purpose-based facilities — created recognition that power supply capacity at the levels required may not be available from conventional sources. Imagination would have to be applied to find a solution for the level of loads being contemplated. Enter nuclear as a way to meet the increased loads.

Many large tech companies are committed to meeting clean energy goals and are searching for viable power supply options to match their growing energy consumption loads and characteristics — such as nuclear. In 2023, an interesting FOAK transaction garnered global attention when announced and offered a potential model for collaboration between a data center developer and a nuclear owner, whether for big box plants, SMRs or micro-reactors. Since then, additional developers and nuclear plant owners have adopted their own unique arrangements under structural and contractual models — simple offtake, retired plant restart, direct existing plant investment and micro-reactor startup investment. [24]

However, the upsurge in nuclear power development is not fueled only by large asset return to service nuclear plant transactions involving previous operating units. Startup power plants have become a surprising source of new transactions and power supply. These transactions reflect a range of different fuel types and intended uses across

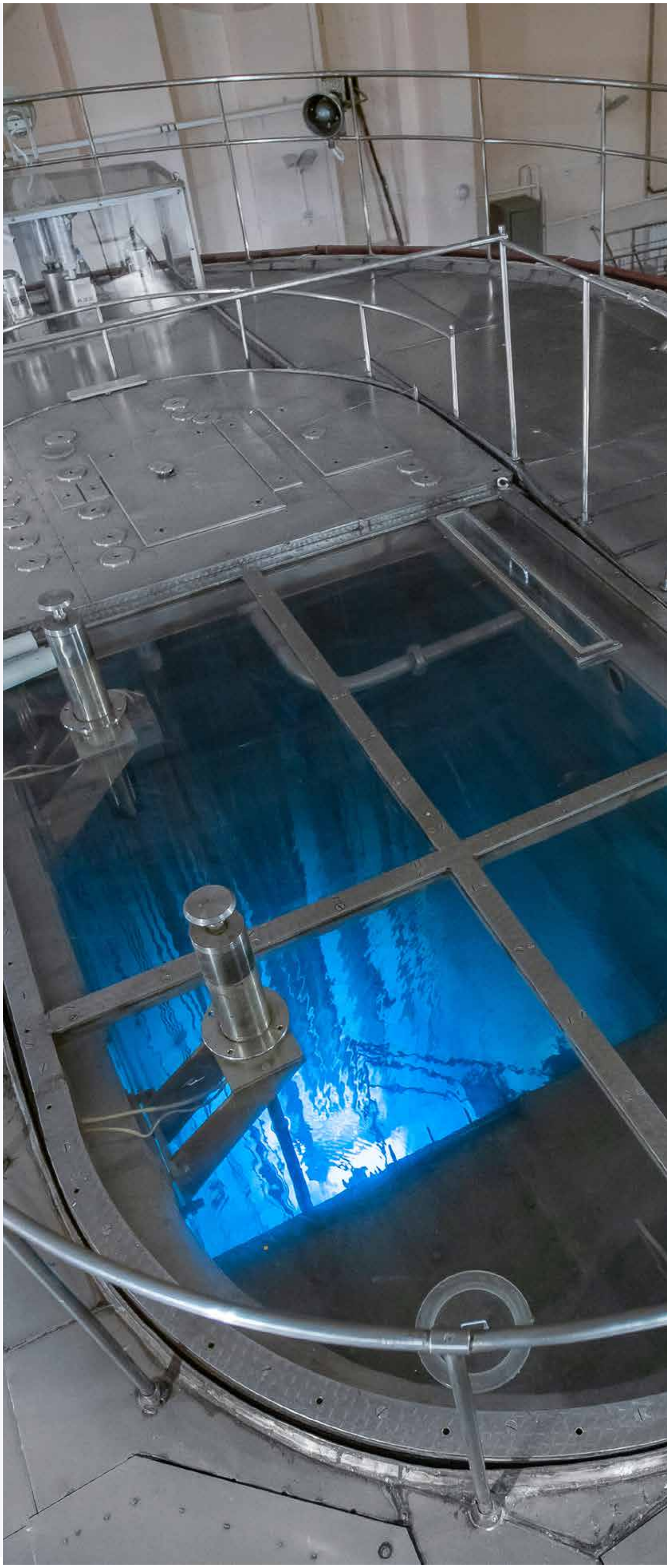
MW scales under 20 MWs for micro-reactors and between 300 MWs and 640 MWs in a standard multi-module SMR configuration.[25]

Micro-reactor and SMR OEMs are forging agreements with multiple types of data center developers and federal government agencies to provide power supply in a variety of settings from smaller generation sets to aggregated multi-GW, multisite installations. These smaller units require less capital financing and can achieve COD far faster than typical big box solutions.[26]

In the near term, restarts of retired nuclear stations are drawing high interest from prior owners, potential acquirors, potential investors and existing operators of nuclear fleets. Some restarts may be straightforward, particularly when the nuclear station has not been out of service for an extended time period. But others could require increased NRC scrutiny depending on plant condition, relicensing requirements and nature of other work.

In the case of finishing an uncompleted and shuttered plant, for instance, site asset conditions and quality of paperwork, i.e., design documents, QA records, etc., could create more significant issues depending on the process utilized to stop work and ready the plant for construction abandonment. In this case, current NRC rules and regulations may have changed since the date work was stopped and require licensing amendment or reapplication or prework to close identified inspection and walk-down issues.

The nuclear sector will need multiple fuel types and scale-level options to complement mega-scale nuclear projects, realize long-term growth and enable the nuclear revival to materialize. The near-term restart of previously shut down nuclear stations may provide the jump-start needed to gain market credibility related to nuclear owner performance. But it will require the success of the first wave of SMRs to capture more market and owner interest than only from data center developers. And the future of nuclear power will not truly gain a firm footing until big box plants can be designed, constructed and delivered at an affordable cost and owners can demonstrate that achieving NOAK cost levels is a reality.



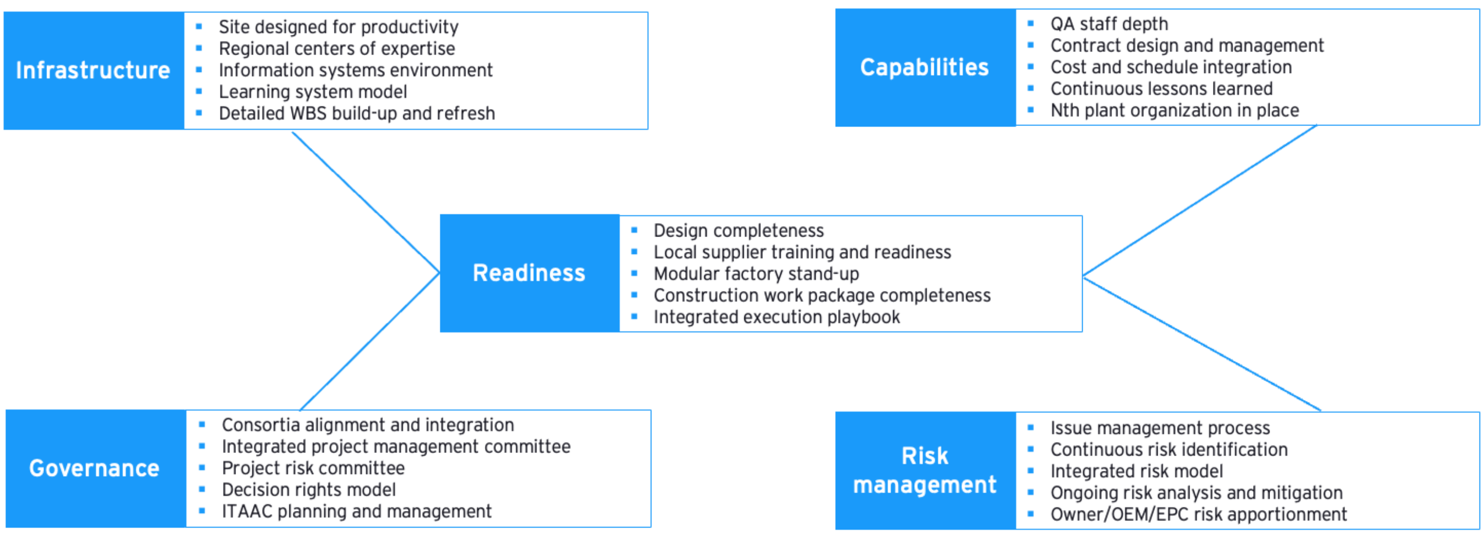
The entire next nuclear journey requires an institutional and structural set of targeted solutions.

The industry and individual owners need to prioritize fixing what hasn't worked, revitalizing what has become outdated, adopting what has evolved and reimagining a new nuclear future to embed a leading project infrastructure, capabilities base and management model. Each of these outcomes contributes to the challenge of how to establish the bases for successful project planning and execution; a well-conceived approach and commitment to full readiness prior to initiating execution.

This objective of enabling nuclear execution readiness is, i.e., utilizing all available early-stage time and resources to confirm project preparation need to be thoroughly conducted before launch and day-to-day performance and sequence are planned in detail, so field work resources are productively deployed. If the requisite preparation work is not adequately performed, then the fundamental outcomes desired are not at the center of an owner's focus and project delivery results and likely not to be realized. (See Figure 14.)

Figure 14: Delivery model building blocks

Project requisites to enable success



Source: EY-Parthenon analysis.

QA = quality assurance; WBS = work breakdown structure; ITAAC = inspections, tests, analyses, acceptance criteria; EPC = engineering, procurement, construction

To move new nuclear from aspiration to reality, developers and owners need to overcome the challenges that exist when taking the first step toward development, as well as facilitating a smooth road to accomplishment. These challenges go well beyond other project stand-up requisites such as standard and simplified design and fully integrated design and construction.

Eight must-have, core predicates need to be in place to drive decisions that can advance the industry's future success:

- **Ownership:** future nuclear plants, or at least those at commercial scale, are unlikely to be economic enough in the near term for individual utilities to afford without a way to spread ownership risks from development through COD and leverage the financial capacity of multiple owners to enable new plants to emerge
- **Consortium model:** the next step beyond shared ownership is to design and adopt a way to partner involving key participants in nuclear development, production and delivery that enables a collaborative and integrated platform to further de-risk execution, from inception through COD
- **Federal financing:** significant up-front federal nuclear funding blended with low-cost government debt or other funding sources for Gen III+ technologies, as well as dramatically expanded research and development (R&D) for Gen IV technologies, is necessary to jump-start and de-risk the next nuclear era
- **Overrun risk:** beyond front-end funding, a formal mechanism needs to be created and funded by the federal government that shields project partners from unavoidable increases to estimated costs that occur over the development and construction lifecycle of the first few plants that reflect the next era of nuclear
- **Portfolio models:** developers and owners need to recognize that stranded nuclear plant development and construction cannot deliver the economies of scale necessary to enable the industry to produce competitively priced energy costs. A portfolio harnesses the benefits of compatible micro-reactor, SMR and big box plants

- **Technological choice:** developers and owners need to decide which technology and project scale will be adopted to establish and build out the common platform for development of the next nuclear portfolio, as well as establish a common family of reactors to support multiple portfolio needs.

- **Risk-based analysis:** early, rigorous and consequential risk analysis anticipates where risks can emerge, what impacts risks can create and how risks can be mitigated. Unlike prior eras, continuous risk assessment should be adopted as an absolute necessity rather than an elective tool.

- **NOAK acceleration:** the underlying imperative for the entire nuclear sector is to establish an environment with a focus on cost management, schedule acceleration and quality execution embedded into the DNA of all participants and reflected in advanced planning and results-driven outcomes.

While each activity has its own degree of significance, the critical path to expand nuclear power in the US runs through Washington, DC, or other country capitals. Without adequate government support and ingenuity in financing options, the path to future nuclear will be difficult to navigate.

The nuclear sector needs to emphasize multiple principles to drive plant development, production and delivery models. These are standardization (fully replicable with a common design basis), simplification (easy to modularly build and maintain) and optimization (highly efficient plant delivery characteristics). These by definition will make projects affordable, indispensable and valuable over their lifecycles.

The emerging era for next nuclear will not be achievable without strong federal legislative and state capital support, plus a mix of creative financing options. The first focus of the federal government has to be to establish a formal financing model that compensates the industry for taking the risks associated with nuclear development, production and delivery, and provides protection early in the development cycle against typical cost overruns that occur in FOAK megaprojects.

A clean set-aside appropriation pegged to cover multiple next nuclear options would provide the core of this financing model. This would establish substantial support to jump-start multiple new projects, while indicating the nature and level of the national commitment to next nuclear development. It will also be important for the sector to work with investors on alternative financing options such as new equity-like offerings, and with regulators on levelized cost recovery.

But the future of the nuclear sector is not assured solely based on the level of financial support and how well the industry executes. Other factors, such as the direction of financial markets, decarbonization, state regulatory policies, design certifications, resource adequacy, and customer affordability, all can impact the total market environment that the nuclear sector must navigate.

Ultimately, the primary objectives for owners are twofold: deliver the next FOAK plants at cost and on schedule, and drive FOAK results to NOAK attainment as rapidly as possible. This is the North Star for the sector and should be the centerpiece of planning and executing each element of the development, production and delivery cycle through a more rigorous lens than previously applied. It may take a moonshot to accomplish this outcome, but the future of "next nuclear" depends on its attainment.

Bibliography

1. World Nuclear Industry Status Report, 9 May 2024, www.worldnuclearreport.org.

2. Johnson, Slade. "Plant Vogtle Unit 4 Begins Commercial Operation - U.S. Energy Information Administration (EIA)." Plant Vogtle Unit 4 Begins Commercial Operation - U.S. Energy Information Administration (EIA)," EIA, 1 May 2024, www.eia.gov/todayinenergy/detail.php?id=61963.

3. Crees, Alex. "The Failed V.C. Summer Nuclear Project: A Timeline." Choose Energy®, Choose Energy, Inc., 4 Dec. 2018, www.chooseenergy.com/news/article/failed-v-c-summer-nuclear-projecttimeline

4. "Olkiluoto Nuclear Power Plant." NS Energy, Business Trade Media International Limited, 18 Jan. 2022, www.nsenergybusiness.com/projects/olkiluoto-nuclear-power-plant/?cf-view&cf-closed.

5. "Authorisation Issued for Flamanville EPR Commissioning." World Nuclear News, World Nuclear Association, 8 May 2024, www.world-nuclear-news.org/Articles/Authorisation-issued-for-Flamanville-EPR-commissioning; Nuclear Newswire, "Another delay, cost bump for Flamanville", January 13, 2022

6. Wikipedia, "Barakah Nuclear Power Plant." Power Technology, April 9, 2020, Dalton, David. "Barakah / Fourth and Final Reactor Starts up at UAE Nuclear Power Station," The Independent Global Nuclear News Agency, NucNet, 1 Mar. 2024, www.nucnet.org/news/fourth-and-final-reactor-starts-up-at-uae-nuclear-power-station-3-5-2024.

7. Calculated from various press stories.

8. Abou-Jaoude, Abdalla, et al, "Literature Review of Advanced Reactor Cost Estimate," page 5, U.S. Department of Energy, Integrated Energy Systems, October 2023, https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_66425.pdf.

9. "Commercializing Advanced Nuclear Reactors Explained in Five Charts," Office of Nuclear Energy, U.S. Department of Energy, 30 Mar. 2023, www.energy.gov/ne/articles/commercializing-advanced-nuclear-reactors-explained-five-charts.

10. U.S. Department of Energy, "Pathways to Commercial Liftoff Advanced Nuclear," pages 1, 18-19 March 2023.

11. Bilicic, George and Scroggins, Samuel, "2023 Levelized Cost of Energy+." Lazard, 12 April 2023, www.lazard.com/research-insights/2023-levelized-cost-of-energyplus.

12. U.S. Department of Energy, "Literature Review of Advanced Reactor Cost Estimates," pages 25-26.

13. U.S. Department of Energy, "Literature Review of Advanced Reactor Cost Estimates," pages 4-5.

14. EY-Parthenon analysis based on press releases and company information.

15. Asuega, Anthony et al., "Techno-Economic Analysis of Advanced Small Modular Reactors," Applied Energy, Volume 334, pages iii, 15, March 15, 2023, Elsevier, www.sciencedirect.com/science/article/abs/pii/S0306261923000338?via%3Dihub.

16. U.S. Department of Energy, Office of Nuclear Energy, "Commercializing Advanced Nuclear Reactors Explained in Five Charts," pages 18-19, 20 March 2023.

17. Bolisetti, Chandrakanth, et al., "Quantifying the Capital Cost Reduction Pathways for Advanced Nuclear Reactors," Systems Analysis and Integration Campaign, U.S. Department of Energy, pages iii, 27, 31, 6 June 2024, https://inldigitallibrary.inl.gov/sites/STI/STI/Sort_109810.pdf.

18. Welter, Kent, et al., "Unique safety features and licensing requirements of the NuScale Small Modular Reactor," Frontiers in Energy Research, vol. 11, 16 April 2023, https://doi.org/10.3389/fenrg.2023.1160150.

19. Melito, Steve, "June 20, 1977 – Oil Flows Through the Trans-Alaska Pipeline System." Global Spec, 20 June 2008, https://cr4.globalspec.com/blogentry/6057/June-20-1977-Oil-Flows-Through-the-Trans-Alaska-Pipeline-System.

20. EY Parthenon, "Financing New Nuclear in Sweden," March 2024, https://www.ey.com/en_se/insights/energy-resources/financing-new-nuclear-in-sweden

21. International Atomic Energy Association, Milestones in the Development of a National Infrastructure for Nuclear Power, Nuclear Energy Series, NG, G-3.1, Rev. 2.

22. Kraev, Kamen, "Turkey / Commissioning Permit Granted for First Unit at Akkuyu Nuclear Station." The Independent Global Nuclear News Agency, NucNet, 15 Dec. 2023, www.nucnet.org/news/commissioning-permit-granted-for-first-unit-at-akkuyu-nuclear-station-12-5-202324.

23. "Olkiluoto Nuclear Power Plant." NS Energy.

24. Various press stories and company press releases.

25. Various press stories and company press releases.

26. Various press stories and company press releases.

EY | Shape the future with confidence

EY is building a better working world by creating new value for clients, people, society and the planet, while building trust in capital markets.

Enabled by data, AI and advanced technology, EY teams help clients shape the future with confidence and develop answers for the most pressing issues of today and tomorrow.

EY teams work across a full spectrum of services in assurance, consulting, tax, strategy and transactions. Fueled by sector insights, a globally connected, multidisciplinary network and diverse ecosystem partners, EY teams can provide services in more than 150 countries and territories.

All in to shape the future with confidence.

EY refers to the global organization, and may refer to one or more, of the member firms of Ernst & Young Global Limited, each of which is a separate legal entity. Ernst & Young Global Limited, a UK company limited by guarantee, does not provide services to clients. Information about how EY collects and uses personal data and a description of the rights individuals have under data protection legislation are available via ey.com/privacy. EY member firms do not practice law where prohibited by local laws. For more information about our organization, please visit ey.com.

Ernst & Young LLP is a client-serving member firm of Ernst & Young Global Limited operating in the US.

About EY-Parthenon
Our unique combination of transformative strategy, transactions and corporate finance delivers real-world value — solutions that work in practice, not just on paper.

Benefiting from EY's full spectrum of services, we've reimagined strategic consulting to work in a world of increasing complexity. With deep functional and sector expertise, paired with innovative AI-powered technology and an investor mindset, we partner with CEOs, boards, private equity and governments every step of the way — enabling you to shape your future with confidence.

EY-Parthenon is a brand under which a number of EY member firms across the globe provide strategy consulting services. For more information, please visit ey.com/parthenon.

US SCORE no. 27686-251US
ED None

ey.com

EY-Parthenon energy and resources strategy consulting teams help energy companies enhance their value today while successfully reshaping their businesses to meet tomorrow's energy needs. Our energy strategists apply the latest technology, leading business practices, state-of-the-art digitization, mergers and acquisitions (M&A) experience and more to help your business transform and thrive.

Authors

Tom Flaherty
Senior Advisor
EY-Parthenon, Ernst & Young LLP
tom.flaherty@parthenon.ey.com
+1 214 208 7129

Mile Milisavljevic
Principal
EY-Parthenon, Ernst & Young LLP
mile.milisavljevic@parthenon.ey.com
+1 713 750 1425

Additional contacts

Jeffrey Miller
Power & Utilities Sector Leader
EY-Parthenon Americas
jeffrey.miller2@parthenon.ey.com
+1 404 817 5879

Stephanie Cutter
Americas Power & Utilities Leader
EY Global
stephanie.chesnick@ey.com
+1 713 750 8192