# MITIGATING FIRST-OF-A-KIND RISK IN SMALL

# MODULAR REACTOR DEPLOYMENT: INSIGHTS

# FROM CONTRACTING APPROACHES

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**Abstract**

Small modular reactors (SMRs) provide a promising solution to the deployment challenges of gigawatt-scale nuclear projects yet concerns over first-of-a-kind (FOAK) risk may deter potential customers. The paper proposes leveraging proven financing and contracting strategies from the renewable energy sector to alleviate FOAK anxiety among energy buyers. Through contracting strategies such as power purchase agreements (PPAs), energy buyers only pay for the clean energy they receive, while developers can ensure revenue clarity and performance accountability, thereby fostering customer confidence in the timely delivery of nuclear energy projects. Through a comprehensive analysis of the potential benefits and practical implications of these strategies, the paper contributes valuable insights on the deployment of FOAK small nuclear reactors.

## INTRODUCTION

Small modular reactors (SMRs) offer a promising solution to the deployment challenges of large nuclear power projects. They are magnitudes smaller, utilize modular manufacturing techniques, and offer flexibility in siting – tenets that ultimately reduce the cost and construction timeframe for SMRs [1]. Recent gigawatt-scale projects, such as Plant Vogtle in the United States, have seen nearly a decade in delays and billions of dollars in overrun costs [2]. While SMRs inherently mitigate many of these concerns, they still present first-of-a-kind (FOAK) risks that could deter customers and financiers and prevent their rapid deployment over the next decade.

Project developers need to be exploring creative avenues to alleviate these risks and anxieties. Adopting an “Energy-as-a-Service” (EaaS) business model paves the way for a more customer-centric approach and allows developers to fully address customer anxiety about FOAK risk. SMR developers can leverage proven financial tools from other emerging energy technologies, such as customer-centric contracting strategies like power purchase agreements (PPAs), which are commonly used for renewable energy systems and also have a history in the nuclear sector with gigawatt-scale power plants.

The paper makes the following recommendations with the understanding that financing and contracting are among the most complex facets of energy infrastructure projects.

## FOAK RISK

While SMRs reduce risks associated with cost and construction, concerns over FOAK deployments may deter potential customers. A FOAK project may be an entirely novel technology, or it may use different design and deployment methods from previous projects, such as incorporating new materials and components or new fabrication and construction methods. It can encompass the entire project or specific elements of the project [3]. In the case of SMRs, there is a wide variety of potential projects with novel elements, ranging from light water reactors to advanced reactors, such as fast neutron reactors, graphite-moderated high temperature reactors, and molten salt reactors – all of which carry different FOAK risk. Considering the project risk associated with the first model of a new generation technology, the costs of a FOAK project are often significantly higher than subsequent commercialized models. These higher costs are often associated with developing supply chains and workforce experience that do not yet exist. However, repeat deployments, known as Nth-of-a-kind (NOAK), are expected to drive substantial cost reductions as the workforce develops and the industrial base scales up [2].

The risk of high upfront technology costs and other market barriers, such as capital constraints for consumers, uncertainty about a technology’s performance, and information barriers, can limit widespread deployment of SMRs. It is critical that customer concerns regarding costs are prioritized as the marketplace evolves.

## Energy-as-a-Service

SMRs offer an opportunity to dramatically expand the reach of nuclear power to new customers and intensive energy users like the manufacturing industry, data centers, and corporate energy buyers [4]. However, it's crucial to recognize that the customer base for SMRs differs markedly from that of large nuclear power plants. Unlike the typical customers of gigawatt-scale nuclear plants, which are often governments capable of assuming substantial risks, the potential customers for SMRs, private industry, have different risk tolerances. Consequently, they are more inclined towards securing deals for NOAK technologies rather than investing in FOAK. Ongoing doubts regarding the economic competitiveness of SMR projects and the ability of project developers to build plants on time and on budget reinforce this customer perspective [5].

Anxieties surrounding FOAK SMRs are one of the biggest risks to delaying new nuclear deployment at a time when clean baseload energy is in critically high demand. To build a strong market, the nuclear industry must respond to and consider customer concerns regarding cost predictability and performance accountability. NuScale Power’s canceled Carbon Free Power Project with Utah Associated Municipal Power Systems lacked subscribers, illustrating that customer buy-in is critical to the success of a FOAK SMR project [6]. These challenges are also applicable to other emerging clean energy technologies yet to be commercialized, such as clean hydrogen, next-generation geothermal energy, and long duration battery storage.

To address the concerns of customers, SMR developers must adopt a more customer-centric approach and adapt their business model for business-to-business sales rather than government-to-government sales. The Energy-as-a-Service (EaaS) offers a framework for SMR developers to provide a more attractive solution for customers. EaaS is a business model where customers pay for an energy service (e.g., electricity) without having to make any upfront capital investment. Instead, all capital for energy production is owned and managed by a service company who delivers the desired energy service [7]. The model establishes a clear and creditworthy economic structure to a nuclear power project, which is critical to obtaining external financing and growing the appetite of customers and investors interested in SMRs.

EaaS has proven successful in expanding deployment of other low-carbon technologies, especially solar and wind power. A prominent example of EaaS in practice is the solar services model for residential solar panels [9]. Instead of paying high upfront capital costs for the installation of solar panels, a homeowner may hire a solar services company to install and maintain a solar system on the homeowner’s roof and sign a long-term contract with the company for the clean electricity generated by the solar system. The solar services provider retains ownership of the system and homeowners may pay for the electricity at a predetermined rate per kilowatt-hour or by a flat monthly fee for the use of the solar panels [7]. The solar services model allows homeowners to avoid the upfront costs of the solar system while still enjoying the cost savings and clean energy benefits of solar energy. At the commercial scale, EaaS can be similarly applied to other clean energy projects, like SMRs.

## EaaS in Practice: Contracting Approaches from Renewable Energy Sector

Looking to the renewable energy sector may provide lessons to incorporate EaaS and overcome FOAK risk for SMRs. One essential financing tool that falls squarely within the EaaS business model is the Power Purchase Agreement (PPA). Though PPAs are most used for renewable energy projects, they can also be applied to other energy technologies such as SMRs. The PPA is known as “the central contract for any independent power generation project, especially in emerging markets” [10].

A PPA is a contract for the purchase of power from a specific energy generator, the seller, to a purchaser of electricity, the buyer. PPAs define all the commercial terms for the sale of electricity between the two parties, including when the project will begin commercial operation, schedule for delivery of electricity, penalties for under delivery, payment terms, and termination [11]. The project may be located on-site at the buyer’s location, known as a physical PPA, or off-site with the electricity being delivered to the buyer through the grid, known as a virtual PPA. Table 1 below further explains how PPAs fit within the EaaS business model.

TABLE 1. PPA ALIGNMENT WITH EAAS BUSINESS MODEL

|  |  |  |
| --- | --- | --- |
|  | Role of PPA | Alignment with EaaS |
| Financing Energy Projects | Third-party ownership of energy assets.  Fixed-rate energy purchase agreement. | Offers predictable energy costs without upfront capital.  Reduces financial burden on the customer. |
| Risk Management | Provider assumes performance and maintenance risks.  Long-term agreements (10-25 years). | Ensures reliable energy supply with minimal customer risk.  Supports long-term customer relationships. |
| Energy Efficiency and Optimization | Can be bundled with energy management services. | Provides a comprehensive energy solution. |
| Scalability and Flexibility | Allows for modular and scalable energy solutions. | Adapts to changing energy needs over time. |
| Innovation and Technology Integration | Access to latest energy technologies. | Offers advanced solutions without customer ownership risk. |

The EaaS business model uses contracting strategies such as PPAs and build-own-operate models, which can strategically shift risk away from customers and provide revenue certainty for project developers and contractors. Through these customer-centric contracting strategies, energy buyers only pay for the clean energy they receive, while developers can ensure cost predictability and performance accountability, thereby fostering customer confidence in the timely delivery of nuclear energy projects. With these enabling financing strategies and contracting approaches, renewable energy has seen rapid growth and achieved commercialization in the last two decades [12].

For the renewable energy industry, PPAs have unlocked small and large-scale commercialization through a few key vehicles. From ​​2010 to 2022, the share of global electricity production from solar and wind climbed from 1.75% to 11.87% [13]. This exceptional growth is largely attributed to falling costs of both solar photovoltaic electricity and onshore and offshore wind electricity [14]. While this growth is supported by multiple factors, including strong policy support and modularization and standardization of technology, PPAs helped enable competitive pricing for renewable energy and increased market access for renewable energy developers by providing a mechanism to sell power directly to buyers. In turn, positive feedback loops from renewable energy growth allow for economies of scale and competitive supply chains to further drive down production costs [14].

Through a service-oriented approach, customers benefit from risk-sharing arrangements where the energy providers assume a significant portion of project risk, including upfront capital investment and performance guarantees. These arrangements enable the host customer to avoid many of the traditional barriers to the installation of on-site solar systems: high upfront capital costs, system performance risk, and complex design and permitting processes. Customers are only financially responsible for the clean energy they receive, and energy developers are incentivized to deliver on time and on budget.

Utilities have traditionally been the primary offtakers for electricity from wind PPAs [15]. However, trends in solar and wind PPA announcements have indicated that corporate energy buyers, led by early adopters such as Meta and Amazon, are an increasingly important clean power buyer group [16]. PPAs are the primary offtake mechanism for corporations, accounting for 80% of contracted clean power offtake by U.S. corporations in 2022, including land-based wind, offshore wind, and utility-scale solar [17]. The popularity of corporate renewables PPAs grew even faster in Europe: between 2022 and 2023, corporate PPA volumes in Europe grew 74% [18]. Clean energy goals set by the European Union and by national governments, combined with volatile energy prices, will further encourage new customers to lock in clean energy PPAs.

The popularity of PPAs have allowed both wind and solar industries to invest confidently with revenue certainty for electricity prices. The U.S. national average price of land-based wind PPAs fell to 2 cents per kilowatt-hour in 2019, allowing for some of the cheapest new electricity generation at that time [19]. For large-scale commercial solar developers, PPAs have proven to be highly popular for on-site commercial solar for all types of customers. In 2019, 45% of U.S. commercial solar capacity was financed by a PPA, and PPAs continue to increase their share of the commercial solar market, largely driven by corporate energy buyers [20].

PPAs can also cover associated renewable energy certificates, which has allowed more customers to invest in the growth of renewable energy, as well as satisfy corporate sustainability requirements [21]. Despite moderately rising PPA prices for solar and wind from 2020 to 2022, PPAs remain attractive for corporate buyers due to high wholesale energy prices and renewable energy goals [17].

### Potential benefits of nuclear PPAs

In the renewables industry, PPAs drive the deployment of new solar and wind capacity by unlocking private investment, and SMRs may benefit from adopting a similar business model. For an industry traditionally financed by government buyers, the strong emphasis on benefits for corporate energy buyers and private industry customers makes the PPA contracting model particularly attractive for adoption within the nuclear industry. Given high perception of FOAK risk, the shifting of risk from customer to power provider may alleviate these FOAK anxieties of customers. One of the key challenges to commercial deployment of SMRs is the ability to raise financing to fund construction – PPAs are poised to help unlock competitive prices and secure revenue certainty.

While renewables PPAs provide many benefits, they must accommodate for the intermittency of renewables which can pose challenges in implementation. While long duration battery storage is in development to enable storage of electricity, storage technologies are not yet widely commercialized [22]. In certain cases, nuclear PPAs can provide more value to customers than renewables PPAs alone. Nuclear energy provides baseload clean energy where the intermittency of renewables can leave gaps in supply for energy consumers in need of 24/7 power. Renewables PPAs can accommodate for intermittency through a Pay-as-Produced PPA, where the payment to the energy producer is based on the actual energy generated and delivered, or through a Baseload PPA, which are structured to provide a fixed amount of energy delivery independent of actual energy production [23]. However, neither of these approaches can guarantee price and production. Baseload renewables PPAs lack certainty as they require supplemental energy from market-priced sources to meet total demand, introducing variability in overall energy costs and putting the energy producer at financial risk. For markets without stable renewable generation or stable energy prices, renewables PPAs cannot provide for baseload needs. Nuclear PPAs, whether physical or virtual, guarantee access to a 24/7 carbon-free power supply and provide protection from energy price volatility. For SMRs and micro nuclear power plants with flexible siting, customers can access additional benefits with a physical PPA. Due to their smaller size, power output, and capacity, SMRs require less space and cooling water, offering greater flexibility in site selection compared to large nuclear plants [24]. This allows for the potential colocation of an SMR with an offtaker, enabling the possibility of a physical PPA. Through a direct wire, also known as a behind-the-meter solution, physical PPAs offer protection from grid instability and the ability to bypass grid connection supply challenges, bolstering resilience and reliability in energy procurement efforts.

In addition to electricity, nuclear power plants also generate heat. In this instance, a nuclear PPA may more closely resemble a contract for a combined heat and power plants or a cogeneration facility, where the agreement may specify terms for the purchase of both electricity and heat. Alternatively, a nuclear developer may arrange for separate PPAs among multiple customers for electricity and for thermal energy. This may be particularly lucrative for emerging heat markets, where there is high demand for district heating systems and industrial processes.

Further, nuclear PPAs uniquely enable corporate energy buyers to track time-matched scope 2 emissions due to the continuous and predictable nature of nuclear power generation. Scope 2 emissions are indirect greenhouse gas emissions associated with the generation of purchased electricity, heat, or steam consumed by an organization. By aligning the reporting of these emissions with the actual consumption of nuclear-generated power, corporate buyers can accurately assess and manage their carbon footprint. See Table 2 for an overview of the benefits provided by physical and virtual nuclear PPAs compared to renewables PPAs.

TABLE 2. COMMERCIAL STRUCTURING

|  |  |  |  |
| --- | --- | --- | --- |
|  | Physical Nuclear PPA | Virtual Nuclear PPA | Renewables PPA |
| Access to 24/7 carbon-free power supply | ✓ | ✓ | X |
| Ability to track time matched scope 2 emissions | ✓ | ✓ | X |
| Protection from energy price volatility | ✓ | ✓ | X |
| Protection from grid instability | ✓ | X | X |
| Ability to bypass grid connection supply challenges | ✓ | X | X |

### Progress of nuclear PPAs to date

PPAs are not new for large nuclear power plants. Take the Akkuyu Nuclear Power Plant in Türkiye, which is scheduled to come online in late 2024 [25]. The forthcoming energy from Akkuyu is financed through a PPA between the builders, Russian construction company Atomstroyexport and Turkish construction company Özdoğu, and the energy buyer, Turkish power wholesaler Tetas, with an average price of 12.35 cents per kilowatt hour for 15 years, covering 70% of electricity production from units 1 and 2 and 30% from 3 and 4 [27]. Akkuyu will be made up of four 1,200 MW VVER1200 units, with the first unit expected to be completed in late 2024 and all four units completed in 2028.

In the United States, recent announcements for nuclear PPAs indicate strong economic signals from electricity demand growth driven by rapid data center development and artificial intelligence, which require 24/7 baseload energy [28]. In March 2024, Talen Energy announced the sale of a data center campus to cloud service provider Amazon Web Services (AWS), which will be powered by 960 megawatts of nuclear energy from Talen Energy’s Susquehanna Steam Electric Station via a 10-year PPA [29]. Demand for baseload energy for data centers is expected to increase dramatically. For the American market alone, demand is expected to reach 35 gigawatts by 2030 [23].

As for SMRs, while a number of future PPA deals have been announced for small and micro nuclear power plant projects in Europe, generally speaking, the use of PPAs in for SMEs is still nascent [26].

### The role of governments

Governments will undoubtedly play a significant role in scaling SMRs through setting policies, offering financing assistance for research, development, and deployment of SMRs, or acting as a customer. As a potential customer, PPAs are attractive to governments for many of the same reasons they are attractive to the private industry.

Policies set at the federal or local level may help or hinder the availability of PPAs for consumers. Regulated utility markets are a prime example. In regulated markets, consumers must purchase power from the local utility, and they may not choose their power provider, restricting the implementation of PPAs [30]. Third-party or direct PPAs may not be allowed or may not be economically viable depending on state and local policies, financial incentives, and utility rates. Regulated electricity markets are a major challenge to the implementation of PPAs. PPAs by non-utility consumers are generally only allowed in competitive electricity markets. Further, if using a virtual (off-site) PPA, the energy generator and buyer must be located in the same power market to allow for physical delivery of electricity [30]. This severely limits the choice available to customers in regulated electricity markets, which reduces market flexibility and competition.

In the European Union, this is less of a challenge due to the liberalization of electricity markets, which requires member states to open electricity markets competitively and allow customers to choose their power suppliers [31]. In the United States, retail electricity markets can be traditionally regulated or competitive, and state policy and electricity market structures dictate what types of financing mechanisms are available. PPAs are allowed in 28 states, Washington, D.C., and Puerto Rico, with varying limitations on system size, specific sectors, utilities, and customer types [32]. In countries with emerging markets for clean energy, some countries with regulated markets such as India, Indonesia, and South Africa, have higher barriers to securing PPAs due to regional patchwork regulations, lack of grid capacity, or monopolies dominated by state-owned utilities [33].

The adoption of PPAs for nuclear energy projects has been raised as a potential vehicle for government procurement of nuclear energy but has yet to gain significant traction due to a complicated economic and legal environment [33]. In the United States, federal agencies are authorized to enter into PPAs via General Services Administration contracting authority, however, they are limited in term to up to 10 years, with some exceptions as demand for renewable energy PPAs has grown [34]. The U.S. Department of Defense is a notable exception and may enter into contracts for up to 30 years for the operation of energy production facilities [35]. Considering higher project development and licensing costs for SMRs and longer development timelines, project developers will likely need longer term contracts for 25 years or more to facilitate financing of SMRs [33]. In 2021, U.S. Representative Elaine Luria introduced the Nuclear Power Purchase Agreements Act, which would require the U.S. Department of Energy to establish a program for long-term nuclear power purchase agreements [37]. Other countries have made similar steps to open limits on PPA term lengths. In 2020, the Czech government passed a law to allow for minimum 30-year PPAs for new nuclear development, which will enable plans for a new reactor at the Dukovany site and support future nuclear projects [38].

## Implications AND Potential Challenges

### 5.1. Bankability

With the EaaS approach, the risk appetite of developers and contractors to take on such responsibility is a major factor. Bankability refers to whether a project will be acceptable to lenders and refers to the scope of consideration of a project seeking project financing in the commercial lending market [10]. The financial security of PPAs may make SMRs more attractive to investors, but both lenders and shareholders will need to accept the creditworthiness of the end customer. One of the main advantages of PPAs is that they provide cost and revenue certainty to the customer and to lenders, respectively, as the price is determined upfront and does not change unless there are agreed-upon variations to the scope of work. However, the developer and contractor bear the risk of cost overruns and must carefully manage the project to ensure profitability within the contracted price. These proposed solutions are intended to address FOAK risk for small and micro nuclear projects in mind and may not appeal at all to energy developers of large nuclear power projects. It’s important to consider right-sizing nuclear energy projects to address the risk appetite of project finance decision makers.

### 5.2. Term length

Conventional PPAs are usually 15 to 25 years and tailored to the operating life of the power plant asset. However, nuclear power plants are designed, constructed, and licensed for much longer terms: the average age of the American nuclear power plants is approximately 40 years old [39]. License extensions on existing reactors indicate that some power plants may continue operations for 80 years or longer [40]. Therefore, nuclear power developers may need to find customers looking for a longer-term solutions for their clean energy needs, or they may need to plan far in advance to identify and secure customers who will take on the energy once the original PPA term ends. However, nuclear energy projects co-located with offtakers creates a strong relationship between power provider and customer, which increases the likelihood of extension or renewal of the original PPA. In addition, nuclear PPAs provide a unique opportunity to lock in very low volatility annual prices compared to conventional power plants. As governments pass legislation to extend the maximum term for PPA contracts, as discussed above, this will help lower barriers to securing long-term PPAs.

### 5.3. Role of project developers

In the wind industry, there are many project developers and few major manufacturers of wind turbines. In 2021, just four turbine manufacturers supplied all the wind power installations in the United States [41]. This ratio of project developers to manufacturers allows for ready access to project development. In the nuclear industry, this ratio is flipped, in that there are many technology vendors but not enough project developers, so technology vendors must take on a project developer role to move their projects forward. Using a build-own-operate model and leveraging the above contracting mechanisms for cost certainty, there are benefits for SMR developers to buy and construct reactors in bulk. As both a technology vendor, manufacturer, and project developer, an entity can maintain control over the orderbook, costs and schedule for delivery of projects. This model would also allow the developer to confidently build out the supply chain and accelerate the learning curve of building SMRs [2]. “Learning by doing,” referring to the experience built across the labor force as it is carried from one project to the next, is the greatest cost reduction opportunity as projects move from FOAK to NOAK [2]. Therefore, PPAs and fixed-price contacting mechanisms may help overcome FOAK risks and accelerate the arrival of cost reductions by NOAK deployments.

## CONCLUSION

These contracting strategies represent a shift towards a more sustainable, efficient, and customer-centric approach to nuclear energy delivery. An expanded customer base for SMRs, combined with high interest from potential new customers, signal a strong order book for project developers, but business strategies must adapt to the needs of an expanded customer base.

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