**FINANCING Deployment of Small Modular**

**Reactors: A risk-based Framework**

**for “Public Private Partnerships 3.0”**

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**Abstract**

This paper makes several assertions to enable more rapid and effective deployment with financing approaches of nuclear Small Modular Reactors (SMRs), with financing approaches to address two priorities of IAEA member countries: A) reducing carbon emissions, and B) enhancing energy security and urban reliability. Financing Advanced Reactors and SMRs must address not only economics, but the critical risks (e.g., reactor and fuel technical performance, regulatory uncertainties, and economics of construction, operations, and ultimately long-term disposal).  Based on structured survey results summarized in this paper, private industry lacks the full capability to address all risks, particularly regulatory uncertainties outside its control.  The public sector and communities must be actively involved in negotiating approaches that enable optimal financing for early build of advanced reactors – as was the case in the 1960s with the first commercial reactor construction.  Responses to the critical risks require *multiple* mechanisms (not just subsidies), under a banner of “Public-Private Partnership 3.0,” involving subsidies, regulatory reform and assistance (including testing), and negotiated risk-sharing and credit support between industry and government agencies.  Subsidies and economics alone are not sufficient; regulatory reform and public investment are vital, and negotiation can lead most importantly to *positive* government budget results, using an “Allied Nuclear Partners” *buy*-side approach, rather than more of a vendor-led *sell*-side approach.

1. MAJOR PREMISES TOWARD “FACILITATING DEPLOYMENT OF NUCLEAR SMRS”

**1.1.** **Tripling nuclear to address climate change**

 The major announcement by 24+ countries at COP28 in December 2023 in favor of “Tripling Nuclear” capacity by 2050 worldwide includes nuclear Small Modular Reactors (SMRs), particularly for industrial applications -- where “deep decarbonization” for steam and heat co-generation poses more difficult challenges. In some cases, better industrial deployments can offer better economics than electrical power production. In China and India local hazardous emissions (PM2.5, SOx, NOx, Mercury) from coal power kill more than one million people a year prematurely in each country, so deployment of nuclear energy can reduce premature deaths. Such public policy challenges could entail hundreds of SMRs for industrial applications, power generation, and district heating in cities, particularly in Europe.

**1.2.** **Massive urbanization**

 Perhaps the greatest challenge is that by 2050, another 3 billion more people will live in cities globally, a *doubling* since 2010 to 6 billion. To function with mass transit, concentrated delivery loads, office towers, high rise apartments, and district heating, cities demand reliable power, heat and cooling 24 hours per day, 7 days/week (24/7). The drive to reduce emissions represents a major policy commitment, but perhaps a larger driver for SMRs is now “dense energy for dense urban loads.” China, India and other countries see deploying SMRs, particularly for cities, and in industrial sectors, as integral to address pollution and these larger societal goals or benefits, not well priced in power delivery.

**1.3. Technology readiness for SMRs with licensing approval**

 Several nuclear SMR designs based on Light Water Reactor (LWR; boiling water or pressured water) technology are ready for licensing and then deployment. Developers are engaged in licensing processes now in North America and Europe. Examples include NuScale, Rolls Royce 1 mid-size SMR (470 MW), the GE-Hitachi BWRX-300, Westinghouse AP300, Holtec 160, and several micro-reactor designs, possibly. In addition, advanced modular reactor designs (AMRs) are preparing for licensing and deployment, and are developing innovative fuel forms and coolants. Many of these efforts already entail forms of public-private partnership.

TABLE 1. SMALL MODULAR REACTOR VENDORS, WITH LICENSING STATUS

|  |  |  |
| --- | --- | --- |
| **SMR Vendor & Model** | **Status of Licensing (in US, Canada, UK)**[ARDP = DOE Advanced Reactor Demo Program]  | **Early possible sites** |
| NuScale 77 MW  | LWR approved (77 MW); Mod expected 2026 | In Ohio (USA), Romania  |
| Rolls Royce 470MW | Expecting ONR Gen’l Design Approval, mid-2026 | Teesside, Wales (UK) |
| GE-Hitachi BWRX-300 | Known BWR design at NRC, CNSC, ONR. 2026 | OPG (Canada), TVA (USA), and in Poland  |
| Westinghouse AP300 | Submitted to NRC and ONR-UK. Expect by 2030 | Possibly ONR UK) |
| Holtec 160 MW | Submitted to NRC, ONR UK. Expect before 2030 | Possibly NJ, MI (US); UK  |
| ARC 100 or Moltex | In Canadian licensing. Strong community support | Pt. Lepreau, NB (Canada)  |
| X-Energy 80 MW  | In US ARDP; working TRISO fuel in TN  | Seadrift, TX with Dow Possibly Hartlepool (UK) |
| TerraPower  | In US ARDP; working sodium fuel at INL | Kemmerer, WY (US) coal site |

 We, and most experts, anticipate no serious “show-stoppers” in licensing approval of some known LWR designs. Several viable SMR designs will be approved by well-established national regulatory authorities before 2028.
Hence, project financing approaches – a major theme in this paper – and serious partnering discussions can occur and are underway now, *before* final licensing approval.

 Manufacturing and installation planning can be done in parallel to gain time toward reducing emissions and meeting urban energy security objectives. Some SMR vendors are raising equity funding based on licensing timelines. Hence, financing models – e.g., multiple customers combining purchased orders for a “fleet buy” -- can be and must be addressed now to accelerate financing. Also, an AMR (210 MWs) is already operating in China and a SMR (35 MW icebreaker ship) is operating off-shore in arctic Russia. Countries in North America, Europe, Africa, Asia, and South America are considering SMRs.

**1.4. Industrial applications (cogeneration) for SMR**

 A substantial increase in interest for SMRs is underway by energy-intensive sectors: chemicals, oil and gas production, mining and metals refining, and to a lesser extent cement and materials,. This increased industrial interest is for applications where high-pressure steam and high heat are required at even more rigorous 24/7 specifications than in the residential electrical power sector. Because the *cost of outages* is much higher in industrial sectors, heavy industry and data centers are more willing to pay for reliable 24/7 zero-carbon steam, heat, and power than current competitive pricing options in the residential power sector. In the USA, electric utilities are more focused on extending 80 GWs of the current nuclear fleet, rather than on building new SMRs for industrial sectors. The US landscape is different.

**1.5.** **Difficulties with a “Renewables Only” Model, and the Real Cost of Outages**

 Wind and solar simply cannot *physically* provide this “always-on” power, nor heat – where countries are seeking always-on sources of energy (or at least dispatchable energy) and industrial decarbonization. Some of the chemical industry in Germany is shutting down, aggravated by price spikes and severe disruptions in natural gas supply.  2
German households pay among the highest electric rates in the European Union. In addition, wind consumes a much larger footprint *per MWh* (not merely per MW) than nuclear by a factor of 200 or more, 3 depending on sites – plus the burden of yet more transmission lines for gathering that power.

 In 2017-20, Pacific Gas and Electric (PG&E) in the USA incurred more than *$20 billion in wildfire damage liability* from transmission lines sparking in high winds in California.4  *None* of these costs were tabulated in LCOE (Levelized Cost of Electricity) computations to approve more wind farms that require long transmission lines, which are needed to reach remote wind farms.

 Lastly, National Renewable Energy Laboratory (NREL) and other evaluators note that LCOE as a metric is useful for comparing progress of a technology over time as it proceeds through readiness levels, but LCOE faces complications and inconsistencies when comparing technologies or energy sources with dissimilar attributes – such as “always-on” dispatchable nuclear power, versus intermittent wind and solar with additional systems costs. 5 Yet many utilities and state commissions use LCOE – perhaps for convenience or simplicity rather than complete cost analysis. Instead, we believe a risk-based model – still mindful of cost dynamics -- outlined in this paper is more complete, and can inform financing negotiations to address critical risks.

2. Risk-based Model for Financing SMRs vs Cost-based Economic Utility Model

 Given the pivotal drivers above, we stipulate that a “risk-based” model for project or SMR fleet financing can offer more insights than the traditional (and limited) cost-based (or “Euros per MWh”) model. 6

The cost-based model suffers significant flaws in negotiating project financing or energy choices:

**2.1. Power system costs**

Power System costs are usually excluded for transmission, backup generation or storage. This is especially egregious in comparing wind sources to nuclear reactors. In most cases, for nuclear plants located at same site as existing utility or industrial facilities, the transmission lines are already in place, or SMRs will be located near loads (within a few kilometers). And in some cases, SMRs will be used to replace older coal-fired power plants, where grid connections are established (e.g., Kemmerer, WY or at Tennessee Valley Authoriy region). Additional shortcomings in cost-only models are outlined in the extensive synthesis study: *Analyzing the techno-economic role of nuclear power in the Dutch net-zero energy system transition* 7

**2.2. Outage costs**

Outage costs are almost never included on intermittent (wind and solar). Outage costs in urban areas or with mass transit are much more significant (and higher) versus suburban residential.8 Outage costs in heavy industry can exceed € 2000 per MWh – far higher than lower residential pricing.

 What are the costs (Fig. 1) of mass transit halted by grid failure at 5pm on a workday, such as in London, on 9 August 2019? Or the massive US blackout of August 2003 from Ohio to New York? Mass transit in New York City failed for nearly a week, and across the entire blackout, more than 50 million people were affected for days.9 The weeklong energy freeze in Texas during February 2021 cost $16 billion in unpaid charges.10 Many large northern cities in USA and Europe have suffered polar vortex events four or more times since 2010.

**Figure 1. What is the cost of outages as more intermittent wind and solar is installed with *more* climate stress?**



Public domain examples compiled by authors

 These outage costs are *not* typically evaluated in weighing nuclear energy versus wind and solar or hydro, which results in flawed cost-based assessments that fail to include the economic risk of such serious events. The traditional “LCOE” utility model does not properly weigh outage costs, because it assumes normal operations. The outage performance record of nuclear technology is superior – the probability of sharp variations in wind and solar generation each day *is 100%, in most regions,* and storage at scale does not exist today. Batteries and storage systems add more costs not well evaluated in electricity markets, especially in competitive pricing power markets.

 The U.S. Energy Information Administration (EIA) has tried to address weakness in only using LCOE, which refers to the estimated revenue required to build and operate a generator over a specified cost recovery period. Starting in 2022, EIA is also looking at “Levelized Avoided Cost of Electricity” (LACE), which is the revenue available to that generator during the same period. [Further Reference: Levelized Costs of New Generation Resources in the *Annual Energy Outlook 2022.* <https://www.eia.gov/outlooks/aeo/electricity_generation.php> ]

**2.3. Project risk framework for negotiating risk-sharing in Public-Private Partnerships**

 For this paper, we adapted a basic project financing risk model into a questionnaire for experts.

Over the last two years, we interviewed experts and executives in the nuclear industry from the U.S. Nuclear Industry Council (USNIC) policy-makers, and other stake-holders knowledgeable in nuclear energy. The basic timeline and staging of risks in three major areas enabled development of the questionnaire.

 The questionnaire (developed by author) is mapped to 34 risks related to financing nuclear SMR projects.
This approach is adapted from author’s experience (ADPaterson, 2007-2012) in the USA Department of Energy (DOE) Loan Program, and work on the “Business Case for New Nuclear Power” conducted at DOE.

 The numbers in circles of Fig. 2 below depict the nexus of each of the specific risks surveyed in the questionnaire grouped in the three primary areas of risk: (A) Technical Risks (In green circles, # 1 to 10); (B) Regulatory and Policy Risks (#11 to 20 in blue); and (C) Market and Finance Risks (#21 to 34 in rose hue).
To delineate the critical risks associated with Nuclear SMR Projects. The critical risks (1 to 34 in the circled numbers) are shown where they occur relative to the project as a market or policy force (e.g., natural gas prices, or interest rates, or subsidies) or as performance by a key actor (e.g., construction by the engineering contractor, or regulatory agency, or state agency, or State-owned Enterprise).

**Figure 2: Project Risk Framework developed by authors using process tracing of case studies**



Source: Project Diagram by author (A.D.Paterson) for IEA meeting, Nov. 2009, based on work at US DOE.

 Intelligent policy can be crafted around these critical risks, informed by field research with experts, who reflect decision-maker viewpoints on the investments needed for advanced reactor projects. Those risks based on this project analysis were then surveyed among selected nuclear industry and policy experts (20), which U.S. NIC can access readily. A table of significant risks ratings from the experts surveyed follows below.

**2.4. Highest and significant risks from expert surveys (2022-2023)**

 Based on 20 expert interviews and ratings in the United States, the major risks were determined to address in financing SMR projects and with policy measures – such as incentives or subsidies for market externalities.

In Table 1, highest risks have the highest numbers in AxB rating. More so in the USA compared to Europe, carbon emissions savings are not rewarded in electricity rates -- nor is steady, dispatchable power, compared to intermittent wind and solar. The very small land footprint of SMRs *per MW-hour*. vs. solar farms or large fields of solar arrays is not valued as highly in North America as in Europe.

TABLE 2: RISKS IN FINANCING SMR PROJECTS



**Technical Risks**

#1) *High plant capital cost* – was widely seen as the highest (most probable) risk with impact for early SMRs, before ramping up production. Manufacturing efficiencies with SMRs are seen as promising, but not current.

#4) *Inflation in basic materials and steel* – is a rising threat due recently to recovery from the pandemic and disruptions of industrial supply chains. Some of this cost increase has crested, but not retreated.

#6) *Multiple suppliers of fuel* is rated a concern, not a show-stopper. Most experts believe that as orders materialize for SMRs, fuel sources will expand to meet demand (not the other way around). Globally there is enough uranium, and fuel conversion is a well-known supply-side manufacturing discipline.

#9) *Lack of veracity of vendor warranties* on reactors. In a previous survey of experts conducted in 2017 with US NIC, some expressed doubt in the scope of warranties. With known LWR designs, this risk is lower.

**Regulatory or Policy Risks**
#13) *Lax emissions rules*: In the USA in 2017 there was more concern that environmental regulations on emissions would be loosened, thereby giving baseload coal plants a longer run. Cheap gas has replaced so much coal now in USA, that coal as a portion of US electricity has slid from 50% in 2007 to barely 20% in 2023 (EIA). In Europe, carbon policies are seen as more durable, and SMRs would now make a large difference in Eastern Europe (such as in the “3SI Region” of the “Three Seas Initiative”. (https://www.3seas.eu/)

#14, #15) *NRC licensing difficulties* (in USA) is still seen as a significant risk for project delays. And, elsewhere, licensing authorities are not well-resourced or staffed for a dramatic expansion in SMR projects.

#17) *Lack of national policy favoring nuclear* – has subsided as a larger concern now that nuclear is included more broadly in Climate Policy, compared to the prior policy battle in Europe from 2015 – 2020.

**Market & Finance Risks**
#21) *Lack of Demand Growth* has subsided as a key risk, compared to ratings in 2017.

#24) *Natural gas prices stay low* – continues to be a risk in USA, but not in Europe or much of Asia.

#27) *Interest rates rise* hindering finance – which has happened since 2022, but they have crested now.

#28) *Electricity rates (revenues) are inadequate* – is a larger concern in North America, than in Europe.

#29) *Financing remains difficult* (more equity, credit support required) – is still rated high, more as a collective of several factors… including regulatory concerns, and adequacy of electricity rates to cover higher capital costs, and construction completion risks.

**2.5. Examples of policy measures to address key risks, enabling improved Public Private Partnerships**

 Three major types of policies offer a robust “toolkit” for a variety of project settings to address critical risks:

*A) Subsidies to address high capital costs*, and low competing natural gas prices. Lower emissions can also be rewarded with feed-in tariffs or by tax credits based on clean energy production.

*B) Regulatory Reform, chiefly at the US NRC*, which is underway, and international regulatory focus on efficient SMR regulatory approval, and more harmony. More certainty is needed to mobilize investment.
In addition, licensing entails a lengthy (four years+) process with substantial filing of technical drawings and materials analysis and reactor simulation. Federal co-funding of the licensing process is needed – for Design Certification, and then for a combined Construction and Operating License (COL). Both are essential.

*C) Credit support* in the form of loan guarantees, e.g., from the existing US DOE Loan Program (enacted as Title XVII in the Energy Policy Act of 2005). Credit support can also take the form of long-term revenue enhancements, or standby reserves to prevent default. Other countries can offer “credit support,” loans with advantageous terms via national development banks, and they can tap regional funds, such as EBRD (European Bank for Reconstruction and Development), or development aid – negotiated around the key risks. And, financing arrangements can be renegotiated also once construction – or installation with SMRs – is completed, and operations have commenced for a couple years. In fact, ownership of the plant can be restructured, using the PPP 3.0 framework, and among public and private share-holders. Credit support is vital for projects overseas in Developing Countries (Africa, South .America, SE Asia).

3. Effective Policy FOR FINANciNG: Public Private Partnership 3.0:
Subsidies + Regulatory reform + RISK ANALYSIS WITH Negotiation

 Public-private partnerships (PPP) have evolved over the years, but can be broken into three classes or perhaps “stages of evolution” or sophistication (PPP 1.0, 2.0, and 3.0), based on their primary elements. Not all public-private endeavors are the same – the level and nature of government involvement and private investment varies. But, particularly with first of a kind SMRs and advanced reactors, the complex set of critical risks must be addressed with multiple mechanisms, including negotiation, *rather than merely offering flat subsidies*, without regard to underlying project risks. Governments in such negotiations can pursue “best value”, rather than only lowest cost.

**3.1. PPP 1.0: Fixed subsidies or incentives to reduce capital costs or reward emissions savings**

 Government grants, tax credits or feed-in “Clean Energy” tariffs – basic subsidies to stimulate more commercial activity, demonstration phase mostly – with minimal attention to regulatory issues or risk analysis – *are not as efficient fiscally*. The production tax credits for nuclear power (Section 45J) in the U.S. Energy Policy Act of 2005 are clearly subsidies -- limited to the first 6,000 MWs placed in operation, and no more than $1 billion per plant.

STRENGTH: Stimulates economic activity and technology adoption (albeit with high cost to the government).

Some kind of value for emissions savings can be monetized, which is not reflected in market prices.

WEAKNESS: Can waste money by over-subsidizing projects that may only need a portion of the amount offered. Projects that may hold little promise of commercial viability without subsidies garner funding; subsidies are a blunt tool.
Fixed tax credits or feed-in tariffs– such as in the U.S. *Inflation Reduction Act 2022* – also fail to account for regional differences in energy prices – as is also seen among regions or countries in Europe and Asia.

**3.2. PPP 2.0: Subsidies + Regulatory reform**

 Grants and subsidies coupled with regulatory reform (e.g., on emissions, on site licensing, or waste) are broader and more effective for new technologies. Debt investors demand regulatory clarity. Regulatory reforms embodied in the U.S. Energy Policy Act of 1992 illustrate such reforms (now 10 CFR Part 52 in USA). Those “Part 52” reforms enabled Early Site Permits (ESP), Design Certification of new reactors, and a combined Construction and Operating License (COL) to avoid the “Shoreham Risk” (1989) of building a reactor, sinking billions of dollars into investment of the facility, and then a state (NY) not permitting its operation. To date, six ESP applications have been filed with U.S. NRC in multiple states, and five have been issued.11  In most other countries, the State owns the site and shares in the plant.
STRENGTH: Better regulatory clarity. The first COLs by U.S. NRC were issued in early 2012 (for the Vogtle and VC Summer plants). Some subsidy is needed for early units that bear additional cost and risks. And regulators like the NRC are addressing ways to streamline environmental, safety, and other reviews, especially after the design has been licensed. And there are requests to license/approve the same design at different sites perhaps with different customers.

WEAKNESS: May not offer enough subsidy or risk mitigation to enable sufficient financing and efficient construction.

**3.3. PPP 3.0: Negotiated Subsidies + Regulatory reform measures + Risk analysis with negotiated credit support**

 In addition to prior approaches, PPP 3.0 addresses risk issues with enhanced loan guarantees; possibly with government preferred equity (with repayments to the government); and insurance or transferrable trust funds. A government agency can offer some kind of negotiated revenue support -- in the United Kingdon (UK) a “contract for differences” is being used on the Hinkley Point C nuclear project, to preserve market pricing generally within the UK grid. PPP 3.0 requires more in-depth negotiation between public agencies and private projects and investors on specific risk-oriented instruments. System performance guarantees remain a crucial mechanism, which may require public sector support for early projects -- enough support to enable private financing.

STRENGTH: Better optimizes scarce government fiscal resources -- *compared to blunt subsidies* -- and improves overall prospects for success of large projects by systematically addressing all risks. Best positioned for large, early or first projects like nuclear power with impacts in multiple sectors (e.g., for electricity, heat, chemical synthesis) – hybrid projects >$1 billion in total value. Transparency and government oversight improve with more detailed documentation. More active involvement by industrial firms like chemical companies and refineries locating SMRs at their facilities offers additional source of financial support and technical and operating expertise.

WEAKNESS: Complex to implement; requires seasoned personnel with finance experience at government agencies. Not suited for thousands of solar projects. Better suited for large, technically complex projects… or fleets of SMRs.

Importantly, PPP 3.0 is what can enable governments to offer more optimal support to first-of-a- kind nuclear energy projects, or to fleets. Via negotiation, risk mitigation can be better tailored to focus government backing in ways which are not only more efficient, but could generate net revenues to government balances. Outside the USA, many utilities are state-owned as larger sources of revenues for governments in smaller countries with poor tax collection systems.

Overall, financing SMRs, especially early deployments, is risk-based, mindful of costs. Three mechanisms are needed: Subsidies, Regulatory Reform, and Negotiation in Public-Private Partnerships with terms mindful of local and national conditions and laws. Government budgets alone cannot fund a “Tripling of Nuclear by 2050” announced at COP28. (from 400 GWs today to 1200 GWs worldwide in the 2050s). Assuming $5 million per MW installed, a tripling of current global nuclear energy capacity – adding equivalent of one million new MWs, including nuclear in industrial sectors -- could entail *more than $5 trillion in financing.* A risk-based framework can better engage and mobilize the trillions in financing needed over three decades from private investment sources in “Public-Private Partnerships 3.0”.

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