**International Conference on Small Modular Reactors and their Applications**

**Topical Group D: Considerations to Facilitate Deployment of Nuclear SMRs**

Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

***DEPLOYMENT OF SMRS:   
A RISK-BASED FRAMEWORK FOR “PUBLIC-PRIVATE PARTNERSHIPS 3.0”***

This paper makes several assertions to enable more rapid and effective deployment with financing approaches of nuclear Small Modular Reactors (SMRs), to address two priorities of IAEA member countries:   
A) reducing carbon emissions, and B) enhancing energy security and urban reliability.

**1. Major premises toward “Facilitating Deployment of Nuclear SMRs”:**

**1.1)** **Tripling Nuclear for Climate Change**: The major announcement by 24+ countries at COP28 in December 2023 in favor of “Tripling Nuclear” capacity by 2050 worldwide included nuclear SMRs, particularly for industrial applications, where “deep decarbonization” for steam and heat co-generation poses more difficult challenges, and in some cases better economics than electrical power production. Iin 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 can reduce those premature deaths. This could entail *hundreds* of SMRs for industrial, electrical generation, and district heating.

**1.2)** **Massive Urbanization**: 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 24h / 7d. 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 in cities*, as integral to address these larger societal goals and pollution threats.

**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, and are engaged in licensing processes now in North America and Europe: Examples include NuScale, Rolls Royce mid-size (470 MW), the GE-Hitachi BWRX-300, Westinghouse AP300, Holtec 160, and several micro-reactor designs possibly. [[1]](#footnote-1) In addition non-LWR reactor designs are preparing for licensing and deployment.

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| --- | --- | --- |
| **SMR Vendor & Model** | [ARDP = DOE Advanced Reactor Demo Program]  **Status of Licensing (in US, Canada, UK)** | **Early 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 | In UK: Teesside, Wales |
| GE-Hitachi BWRX-300 | Known BWR design at NRC, CNSC, ONR. 2026 | OPG (Canada), TVA (USA), in Poland |
| Westinghouse AP300 | Submitted to NRC and ONR-UK. Expect by 2030 | Possibly in UK (ONR) |
| Holtec 160 MW | Submitted to NRC, ONR UK. Expect by 2030 | Possibly NJ, MS (US) |
| ARC 100 | In Canadian licensing. Strong community support | Pt. Lepreau, NB (CAN) |
| X-Energy 80 MW | In US ARDP; working TRISO fuel in TN | Targeting Hartlepool, UK |
| TerraPower | In US ARDP; working sodium fuel at INL | Kemmerer, WY coal site |

We anticipate no serious “show-stoppers” in licensing approval of several known LWR designs. Several viable SMR designs will be approved by well-established national regulatory authorities before 2028. Hence, we believe 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 also 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 SMR (210 MWs) is 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 for SMRs**: A substantial shift in focus for SMRs is underway toward heavy energy using sectors: chemicals, oil and gas production and refining, metals and mining, and to a lesser extent cement and materials, where steam and 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 heavy industrial sectors, heavy industry and data centers bring more willingness to pay for *reliable* 24/7 zero-carbon heat, steam and power than current competitive pricing for fossil fuel or intermittent options. Note that in the past utilities in the USA and some other countries are more focused on extending 80 GWs of the current US nuclear fleet, rather than building new SMRs for industrial sectors.

**1.5)** **Failure of a “Renewables Only” Mode, and the Real Cost of Outages:** A “Renewable Energy (RE) Only” approach by some larger countries (e.g., Germany’s *EnergieWende*) has failed. Wind and solar simply cannot *physically* provide this “always-on” power, nor heat, at any price. Wind consumes a much larger footprint *per MWh* (not merely per MW) than nuclear by a factor of 200 or more [[2]](#footnote-2), depending on sites – plus the burden of yet more transmission lines for gathering that power. In 2017-20, PG&E incurred more than *$20 billion in wildfire damage liability* from transmission lines sparking in high winds in California. [[3]](#footnote-3)

*None* of these costs were tabulated in LCOE computations to approve more wind farms that require long transmission lines, which are needed to reach remote wind farms.

Nor can wind or solar deliver heat and steam effectively for industrial applications. Some of the chemical industry in Germany is shutting down over this failed model, aggravated by price spikes and severe disruptions in natural gas supply. [[4]](#footnote-4) Iin Germany, major news publications decried the failure of the EnergieWende to deliver reliable or affordable power… Germany sees the highest electric rates in the EU.   
 [Die Zeit: “Schmutziger Irrtum” or “Filthy Blunder”, Dec. 2014]

[www.zeit.de/2014/50/schmutziger-irrtum-energiewende-klimawandel](http://www.zeit.de/2014/50/schmutziger-irrtum-energiewende-klimawandel)

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

Given these pivotal drivers above, we argue 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. [[5]](#footnote-5)

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

**2.1)** **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 the transmission lines are already in place, or SMRs will be located near loads (within a few KMs), and some on older (coal-fired) power plant sites, where grid connections are established (e.g., Kemmerer, WY or at TVA).

**2.2)** **Outage costs** are almost never included on intermittent resources (wind and solar). Outage costs in urban areas or with mass transit “cost per KWh” are much more significant versus suburban residential. [[6]](#footnote-6) Outage costs in heavy industry can exceed >€ 2000 per MWh – far different than lower residential pricing.

What is the cost of a mass transit system halted by grid failure at 5pm [London 9 Aug., 2019] on a workday?

Or the massive USA blackout of Aug. 2003 from Ohio to New York. Mass transit in New York City failed for several days, and across the entire blackout, more than 50 million people were affected for days. [[7]](#footnote-7)

Or the weeklong USA energy freeze in Texas during Feb. 2021, which cost $16 billion in unpaid charges. [[8]](#footnote-8)

**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” (Lowest Cost of Electricity) 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, and that would add more costs not currently evaluated in electricity markets.

**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 US Nuclear Industry Council, 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 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 force (e.g., natural gas prices, or interest rates) or as performance by a key actor (e.g., construction by the EPC Contractor, or regulatory agency, or state agency).

A diagram of a project

Description automatically generated

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

Those risks based on this project analysis were then surveyed among selected experts (See Questionnaire with the same 34 risks depicted in the project diagram above. A table of significant risks ratings from the experts surveyed follows below.

Sample interview questionnaire conducted with 20 experts (2022-2023) for this paper.

[Matches project diagram on previous page (34 designated risk points in project)]



**2.4 Highest and Significant risks from Expert Surveys (2022-2023)**

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

Highest risks are have red font 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 as in Europe.

A screenshot of a computer

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**2.4.1 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.

**2.4.2 Regulatory or Policy Risks**

#13) *Lax emissions rules*: In the USA, back 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. 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.   
  
**2.4.3 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, whether electricity rates can cover higher capital costs, and construction completion risks.

**2.5 Plot of Significant Risks to Nuclear Project Success for Negotiation** (from table above)



Source: chart developed by author from Expert Survey ratings conducted by the author,   
as summarized above in the table of Impact vs Likelihood, two dimensions of risk.]

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

**2.6 Examples of Policy Measures to address key risks, which enable “PPP 3.0”**

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 from the existing 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.

**3. Effective Policy: Public Private Partnership 3.0 –Subsidies + Regulatory reform + Negotiation**

Public-private partnerships (PPP) have evolved over the years, but can be broken into three classes or perhaps “stages of evolution” or sophistication, 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 economics.

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

Government grants, tax credits or feed-in 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 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.

PRO: 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.

CON: Can waste money by over-subsidizing projects that may only need a portion of the amount offered, . and projects that may hold little promise of commercial viability without subsidies get funded. It is a blunt tool. Fixed tax credits or feed-in tariffs– such as in the *Inflation Reduction Act 2022* – also fail to account for regional differences in energy prices.

**3.2 PPP 2.0: Subsidies + Regulatory Reform**

Grants and subsidies coupled with regulatory reform (e.g., on emissions, on site licensing, waste).

Debt investors, in particular, 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. So far, six ESP applications have been filed with NRC in multiple states, and five have been issued. [[9]](#footnote-9)

PRO: 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 request to license/approve the same design at different sites perhaps with different customers)

CON: May not offer enough subsidy or tailored risk mitigation to enable full financing and construction.

**3.3 PPP 3.0: Negotiated Subsidies + Regulatory measures + Risk analysis with credit support**    
In addition to prior approaches, enhanced loan guarantees; possible government preferred equity (with pay-backs to the government); 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.

PRO: Better optimizes scarce government fiscal resources, and improves overall prospects for success of large projects by systematically addressing all risks. Best positioned for large, “first of a kind” 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.

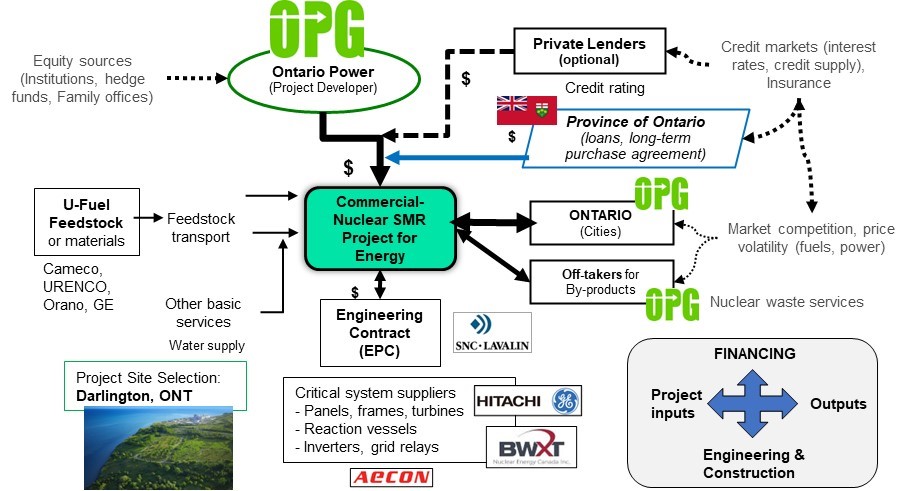
A government agency can offer some kind of negotiated revenue support; in the UK a “contract for differences” is being used on the Hinkley Point C nuclear project, to preserve market pricing generally within the UK grid.

CON: Complex to implement; requires seasoned personnel with finance experience at government agencies. Not well suited for thousands of solar panel 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.

**APPENDIX: Sample SMR Case Studies illustrating Risk Framework and PPP 3.0 elements**

**Case Study: OPG installing 4 SMRs (GE-Hitachi BWRX-300s) at Darlington site in Ontario, CAN**



Construction agreements with SNC-Lavalin and AECON, plus BWXT-Canada on key elements.

<https://www.power-eng.com/nuclear/opg-expects-nuclear-construction-on-first-smr-to-begin-in-2025/>

Nuclear fuel agreements with OPG

<https://world-nuclear-news.org/Articles/SMR-fuel-supply-chain-grows-as-agreements-signed>

**Case Study: NB Power installing ARC-100 advanced SMR at Point Lepreau site, NB (CAN)**

A diagram of a power plant

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**Partnership [PPP 3.0] for ARC-100 commercialization, 02 May 2024**

A trilateral collaboration agreement has been signed to further cooperation between Korea Hydro & Nuclear Power, ARC Clean Technology and New Brunswick Power.

https://world-nuclear-news.org/Articles/Partnership-for-ARC-100-commercialisation

Abstract Submittal to IAEA

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TOPIC D.15

**Topical Group D: Considerations to Facilitate Deployment of SMRs**

This topical group will focus on how nuclear infrastructure development can create an enabling environment to facilitate deployments of SMRs. These include energy planning to meet energy demand and climate goals, integration of SMRs in energy systems with large shares of renewables, nuclear infrastructure including capacity building, stakeholder engagement, financing, cost and economic appraisals, contracting approaches, revenue models for demonstrating business case and viable deployment and business models, e.g., interactions amongst vendors, utilities, end users and other stakeholders. This area will also include international cooperation for harmonization and standardization.

**Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects** (D.15)

Estimation, analyses and optimization of development costs, construction and operations expenses of SMRs; Revenue models for demonstrating business case and securing access to funding and financing; Macroeconomic impact of SMR development; Lifecycle cost of operating and decommissioning SMRs; Viable deployment and business models of SMRs; Economics of SMRs for repurposing retiring fossil-based plants.

**Abstract**

***Deployment of SMRs: a Risk-based Framework for “Public-Private Partnerships 3.0”***

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, private industry lacks the full capability to address all risks, particularly regulatory uncertainties outside its control.  The public sector (agencies, 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, 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 over the life of the financing, using the ”Allied Nuclear Partners” BUY-side approach.

**Keywords**:  Financing, Advanced reactors, Critical risks, Public-private partnerships, SMR

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