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TASK FORCE REPORT

Aligning Public Finance Policies with Technology Readiness Levels in Clean Energy Technologies

By **Dr. Tom Moerenhout** and **Sofia Parker**

Task Force Chairs: **Wally Adeyemo, Michael Bruce, and Dave Turk**

September 2026

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Tom specializes in the intersection of geopolitics and industrial policy, particularly as they relate to energy, critical minerals, and battery supply chains. His work focuses on integrating the interests and influence of multiple actors across complex political economies to improve supply chain security and resilience. Tom has published extensively on sustainable development and energy policy reforms, specifically on energy subsidies, critical materials, and the economic development of resource-rich countries.

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Tom holds two master's degrees and obtained his PhD at the Graduate Institute of International and Development Studies in Geneva. This academic background includes fellowships at LSE and the Oxford Institute for Energy Studies. He was also a Fulbright and Albert Gallatin Fellow, and a Swiss National Science Foundation Scholar.

In his downtime, Tom enjoys reading & writing, culinary experiences, football, skiing, and chess.

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Executive Summary

Over the past decade, governments in developed economies have expanded the use of public financing tools to support the development of clean energy and critical materials technologies. Instruments such as grants, concessional loans, guarantees, offtake arrangements, and tax credits have been deployed to address climate, energy, supply chain, and geopolitical objectives. As technologies evolve from early research through demonstration and then commercial scale, policy effectiveness changes depending on the instrument used. This task force report, which synthesizes insights from two expert roundtable discussions on the past decade of US industrial policy, highlights key lessons on how governments can sequence public finance tools as technologies and projects mature.

Key findings of this report include the following:

- Technology development and deployment failures can stem not only from insufficient amounts of government support but also from the misapplication of instruments as technology risk profiles change. The same instrument can be effective at one technology readiness level (TRL) but less effective at another.
- To ensure that policy tools are targeting the specific risk at hand—whether it be technical and scientific risk, execution and performance risk, or scale-up and commercial risk—governments need to recalibrate public support at each development stage.
- For technologies at early stages of development (TRL 1–3), such as plasma separation for rare earth elements or direct internal recycling for nuclear fusion, distributing small and flexible grants across a large number of participants allows multiple technological pathways to be pursued simultaneously. Tolerating some level of "failure" across a portfolio of projects is a design requirement, not a weakness.
- For technologies at middle stages of development (TRL 4–7), such as small modular reactors or superhot rock geothermal, cost-sharing agreements can outperform straight grants by enhancing incentive alignment and introducing outside commercial discipline. This stage requires industrial policy that addresses both the expensive and risky first-of-a-kind (FOAK) construction needs of TRL 4–7. Sliding-scale cost-share ratios reflect the risk level of the recipient, and milestone-based technical validation by public agencies can operate as a financing instrument by providing private capital with a credible signal of technical viability.

- For projects at later stages of development (TRL 8–9), such as conventional mineral extraction and lithium iron phosphate battery manufacturing, revenue stabilization instruments are critical for securing the substantial project finance debt typically required for projects in this phase. Permitting and regulatory uncertainty can also become more binding constraints than residual technology risk at this stage.
- Political durability of public programs that support the ability of technologies and projects to secure financing requires deliberate institutional design. Arm's-length lending agencies, credible public narratives about acceptable failure rates, and multiyear program authorization can help industrial policy programs survive political cycles.

1. Introduction

Governments in developed economies have deployed a growing tool kit of public financing instruments in the past decade to advance clean energy and critical materials technologies and projects. The effectiveness of these policy tools shifts as technologies move from early research to demonstration and then to commercial-scale projects. Getting the sequencing of policy tools right across these development phases can support the efficacy of public programs.

The Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL); the Inflation Reduction Act (IRA); and the CHIPS and Science Act (CHIPS) included appropriated and authorized funding of $1.2 trillion over 5–10 years to a wide range of industries and recipient types, from large corporations and utilities to research labs conducting early-stage R&D.[1] Though only a fraction of this funding was actually deployed and a significant portion of the IRA has now been rescinded, the scale of ambition—at just under 5% of US GDP in 2022—was roughly equivalent to total federal spending on Social Security in that same year.

The Center on Global Energy Policy (CGEP) at Columbia University SIPA and the New Energy Industrial Strategy Center (NEIS Center) conducted two closed-door expert roundtables in 2025 to reflect on lessons from the BIL and IRA experience, with some discussion of international policies as well. The roundtables brought together approximately 60 participants from across the clean energy technology, investment, and policy ecosystem, including technology and project developers in geothermal, nuclear, batteries, minerals, and renewables; original equipment manufacturer (OEM)-adjacent actors; venture and growth equity investors; infrastructure and project finance investors; and former senior officials from US government agencies. One roundtable, held in Palo Alto, California, focused on early-stage technologies, pilot projects, and first-of-a-kind demonstrations. The other roundtable, held during New York Climate Week, focused on later-stage technologies and commercial scale-up.

A key theme from the roundtables was the importance of sequencing: Successful industrial policy is not just about the magnitude of support but also about matching the right public finance instrument to the relevant binding constraint at different technology readiness levels (TRLs). At early stages of technological development, uncertainty is largely conceptual and scientific, so only highly strategic private capital will engage. Therefore, direct government support such as grants are often needed for a technology to evolve. At intermediate stages, technical and scientific feasibility is established with risks centered around demonstration, performance, and cost competitiveness. At this stage, tools such as cost-sharing agreements can mobilize private capital and introduce incentive alignment for the recipient. At later stages, the dominant risks are related to construction and markets and whether the project can be commercially profitable at scale. At this stage, revenue stabilization measures that support bankability are critical. These measures can range from contracts for difference to direct government offtake agreements.

There is a significant literature on public financing instruments for the energy transition as they relate to scale (*how much?*), target recipients (*to whom?*), and design (*with what?*). This task force report, grounded in insights from the two roundtables, deepens this literature by narrowing in on how the question of design (*with what?*) changes as technologies and projects mature. The report also considers new ideas for public finance instruments to support current energy transition challenges.

Section 2 of this report groups TRLs into buckets of development-stage challenges as well as financial instruments into families with similar support attributes. This framework is used in Sections 3–5 to match each technology development stage with the policy tools that most readily address its specific challenges. This is followed by consideration in Section 6 of how conditionality can be and has been embedded in these policy tools. Section 7 examines policy tools that have been deployed across five clean energy clusters: mineral extraction and processing, battery manufacturing, wind and solar, geothermal, and nuclear energy. Section 8 concludes with some broader insights on how industrial policy design might be made more durable and administratively effective.

While this paper draws on international experiences from developed economies, it is largely based on reflections from the US context. Two points are worth highlighting. First, this report applies to scenarios in which policymakers have determined that a "market-led" approach—where private capital will lead project development rather than the state assuming full ownership or control—is appropriate. Second, the financing instruments considered largely fall under the category of "de-risking," in that they alter incentives by targeting the risk-return calculation of private capital. This contrasts with measures that directly target the allocation of capital, such as larger or full government ownership of projects, sector lending quotas, capital charges, and central bank purchasing programs. It also contrasts with trade measures such as tariffs or import quotas.

There are situations and jurisdictions in which more direct-targeting, government-centered approaches may be appropriate and feasible given the prevailing political economy. This paper does not wade into debates around industrial policy approaches and is meant as a guide within a specific techno-economic paradigm rather than an endorsement of the paradigm itself. There was overall consensus at the roundtables, however, that radical thinking and action on the political economy of industrial policy are needed to meet the crisis of the moment.

2. Analytical Frameworks: TRL Buckets and Instrument Families

The TRL framework was originally developed by NASA in the 1970s to describe technical maturity in a narrow sense, but its use has now widened to include broader risk categories (e.g., market risks) that remain unresolved in a technology or project's development. Across the roundtables, discussion repeatedly converged on the same underlying question: At each stage of development, what risks dominate, and who is the right party to bear them? While, in practice, risks are not rigid and can overlap across stages, TRLs are useful for thinking through what risks public and private capital are typically being asked to solve for at each point in a technology's development.

For the purpose of this report, TRLs are grouped into three buckets:

1. **TRL 1–3:** early research and proof-of-concept activities, including basic research, laboratory validation, early prototypes, and predemonstration experimentation.
2. **TRL 4–7:** pilot, demonstration, and first-of-a-kind (FOAK), pre-full-commercial-scale projects. Here, technologies have been validated in the relevant environment, but their executability, cost, and performance at commercial scale remain uncertain.
3. **TRL 8–9:** commercial-scale buildouts and deployments. Technologies have been technically demonstrated and are capable of reliable performance but face construction, scale-up, cost competitiveness, market, and regulatory risks.

Projects may straddle TRL buckets or move nonlinearly between them. For example, a minerals project may involve TRL 5 processing methods alongside TRL 9 extraction technologies. Table 1 demonstrates how key uncertainties, binding constraints, and appropriate policy tools evolve across TRL stages.

Table 1: Technology readiness level (TRL) analytical framework

	TRL 1–3	TRL 4–7	TRL 8–9
Technology stage	Early R&D and proof of concept	Pilot and demonstration	Commercial-scale deployment
Key uncertainty	Is it technically feasible?	Can it perform in real-world conditions?	Is it commercially viable?
Binding risk constraints	Technical and scientific feasibility	Execution and performance	Scale-up, market, and regulation
Policy tools (not exhaustive)	Grants, equity, cost-sharing agreements	Cost-sharing agreements, grants, loans	Loans, tax credits, contracts for difference, feed-in tariffs

2.1 Matching Policy Instruments to Binding Constraints

TRLs provide a practical way to align financing instruments with the binding constraints faced at different stages of development. At TRL 1–3 (early research and proof of concept), the dominant risk is technical uncertainty, when there is a limited line of sight to commercial cash flows. At TRL 4–7 (pilot, demonstration, and FOAK projects), the technology's performance has been validated in controlled settings but is not yet proven at commercial scale. At TRL 8–9 (commercial-scale deployment), the technology or project faces construction, scale-up, market, regulatory, and geopolitical risks.

At TRL 1–3, the central challenge is ensuring sufficient risk-tolerant funding for iterative experimentation, including the many pathways that will not succeed. Public R&D grants are an effective instrument, with design mattering as well as size. Flexibility to pivot R&D direction in response to early results is important. Speed of administration and approval is also of strategic importance, particularly in the context of geopolitical competition. Overbureaucratized programs can directly undermine the risk-taking they are intended to support.

At TRL 4–7, technologies are scientifically feasible but not yet commercially viable. Instrument suitability shifts from pure grants toward cost-sharing agreements that require significant private co-investment. Sliding-scale cost-sharing can reflect the recipient's risk profile, with private cost-sharing increasing as projects approach commercial viability. Technical validation by public agencies as a condition to funding disbursement can also act as a quasi-instrument by sending a de-risking signal to private capital. Political durability of programs is especially critical at this stage, as projects operate on multiyear development timelines.

At TRL 8–9, the dominant challenge is bridging the gap between the rigid investment parameters of project finance[2] lenders and the riskier characteristics of new commercial-scale projects. The dominant risks shift from technological feasibility and performance to ensuring commercial viability. Key policy tools include revenue stabilization instruments such as contracts for difference, price floors, and long-term government offtake agreements that can unlock private capital. Concessional loans and loan guarantees are also appropriate for strategically important projects, as are contingent facilities[3] such as reserves that can be drawn on if specific risks materialize. Finally, permitting uncertainty and regulatory delay can be a more binding constraint to project finance than residual technology risk.

2.2 Grouping Policy Tools into Six Instrument Families

Government policy tools to support financing can be grouped into six instrument families that reflect shared characteristics of the instruments rather than shared relevance to TRLs (see Table 2). The main focus of this report is on instrument families 1–4 because they directly provide finance or support the ability of the recipient to secure financing. However, there are several challenges, such as foreign currency risk and permitting, that are not easily reducible to concepts of risk and return but still represent major barriers to financing, and measures to address these are included in instrument families 5 and 6.

Table 2: Government instrument families to support financing

Family	Instruments	Summary purpose
Upfront capital support	Grants, cost-sharing agreements, concessional loans, loan guarantees,	Reduce the amount of private capital that needs to be raised and/or provide downside protection.
Revenue enhancements	Investment tax credits, production tax credits, accelerated depreciation, royalty reductions or holidays.	Improve project economics once there is an established line of sight to mobilizing private capital, yet challenges remain around the cost of that capital or securing the amount required.
Revenue and price stabilization	Feed-in tariffs, contracts for difference, forward contracts, advance market commitments.	Address risks from low, uncertain, or volatile market prices and demand.
Offtake and procurement	Direct government purchases, demand aggregation, strategic stockpiling, long-term procurement commitments.	Anchor demand when there is lack of an established offtake market. Often solving for the same type of commercialization challenges as revenue and price stabilization instruments, these instruments directly purchase the underlying physical product as opposed to managing volatility in pricing and demand.
Risk mitigation	Political risk insurance, completion guarantees, foreign-exchange and local-currency facilities, other forms of contingent support.	Particularly important for cross-border projects and for technologies exposed to regulatory or geopolitical uncertainty.
Other enabling tools	Permitting fast tracks, land subsidies, energy subsidies, trade measures, exploration support.	While not financing tools per se, these instruments shape the broader development and investment environment and can be critical for securing financing.

Note: Relevance of the family increases from top to bottom as the TRL stages progress.

A description of each policy tool is included in the appendix.

3. TRL 1–3: Public Capital to Absorb Technical Risk

At TRL 1–3, technologies face a combination of high technical uncertainty and a limited line of sight to bankable cash flows. At this stage, it is often unclear whether a given process will function outside controlled laboratory conditions, let alone whether the technology can be scaled or integrated into existing systems. Early-stage technologies often require experimentation across multiple technical pathways and tolerance for dead ends. As a result, conventional financial metrics such as cost of capital, payback periods, or revenue projections are largely irrelevant.

The role of private capital at this stage depends on incumbency in the existing market. When an established player has potential upside and there are synergies from investment in a new technology, corporate balance sheet funding may support R&D through strategic equity investments. This could come from the seller or potential buyer of the end product. A good example of this is automotive OEMs investing in early-stage battery development. Venture capital may engage at TRL 1–3 in exceptional cases, particularly where technologies align with longer-term strategic investment views on a particular sector or technology.

At TRL 1–3, governments generally need to step in to bridge the risk of early-stage technological development, given the high likelihood of failure and multiple-year time horizon. The central challenge at TRL 1–3 is ensuring that sufficient risk-tolerant capital is available for technical learning across a portfolio of opportunities, as opposed to singular projects, and that some level of recipient "failure" is normalized. This typically comes in the form of upfront capital support, such as grants and equity, and in cases where private capital is available, cost-sharing agreements are also relevant. Warrants, which are equity options typically exercisable at zero cost to the owner, can also accompany grants or other forms of support to provide future upside sharing for the government.

Select TRL 1–3 Examples

- **Mineral extraction and processing:** High-temperature plasma separation for rare earth elements is an early-stage processing technology that is undergoing fundamental research in laboratory settings in the US. The technology has not been demonstrated at a pilot scale, and no continuous or operational industrial systems exist.
- **Next-gen battery manufacturing:** Next-generation solid-state battery technologies largely remain in early TRL stages in the US. Core challenges are proving the materials science, manufacturability, and long-cycle durability. Much of the work remains at proof-of-concept and laboratory validation stages.
- **Nuclear:** Several nuclear technologies are still in the proof-of-concept stage in the US, falling largely in the TRL 1–3 bucket, such as direct internal recycling for nuclear fusion.

3.1 Perspectives from Project Developers and Investors

Roundtable participants consistently identified public R&D grants as the most effective instrument at TRL 1–3. Grant funding from public agencies, universities, and national laboratories was described as essential for supporting basic research, early prototypes, and proof-of-concept work that is unlikely to attract private financing.

Philanthropic capital—prizes as well as incubators and accelerators (programs that support early-stage ventures through funding, mentorship, and networks)—are useful complements to public R&D funding. Participants noted that these pools of capital can support exploratory work, help build technical teams, and fund high-risk concepts that fall outside traditional government programs. However, such initiatives are piecemeal and do not provide the signaling of policy direction and targeted support required for the development of a robust R&D ecosystem.

Roundtable participants repeatedly stressed that flexibility of funding milestones is critical. Flexible grant terms that enable R&D work to pivot in response to early results were highlighted as essential for success because they allow developers to adapt to the inherently iterative and uncertain path of research. Small grants with clear but flexible technical objectives were often viewed as more effective than larger, more rigid funding packages.

Selective use of strategic government equity stakes was also discussed at the roundtables.

Participants emphasized that government equity can be particularly well suited to supporting early spinouts, as there is not yet cash flow to service debt. Spinouts are when a new entity is separated from a larger parent organization, typically a corporation or a research institution. This separation is done to commercialize a specific technology, idea, or piece of intellectual property or in situations where existing assets have value but their commercialization remains risky.

At TRL 1–3, shareholder dilution concerns from government equity are secondary, given the high-risk profile of the recipient. Existing shareholders, if there are any, are typically more concerned with the risk of their investment succeeding at all. However, participants noted that when governments do hold equity, a clear framework around governance rights, investment timeline, and exit pathways becomes critical for raising private capital at later TRL stages. In this context, a well-articulated strategy by the government can provide clear insight on how it views its short-, medium-, and long-term role as equity investor. Participants also emphasized that early-stage equity investments should avoid rigid valuation approaches that may distort technical decision-making and discourage exploration of different technological pathways.

A recurring concern at the roundtables was the negative impact of heavily bureaucratized government programs on startups, which have limited time, cash, and bandwidth—resources needed to comply with slow and complex government processes. Participants described cases in which slow approval processes, excessive reporting requirements, or inflexible program rules undermined the very risk-taking the policy instruments were intended to support. One participant noted that in China the time from application to disbursement for their equivalent grant program was 3 months, whereas in the US it was 12 months, and that this difference was critical to their start-up race.

An additional concern involved migration policy. Roundtable participants said the inability of companies to provide multiyear visas for foreign researchers is lowering US attractiveness to candidates vis-à-vis other countries that have a well-established R&D ecosystem, including China.

Overall, participants converged on the view that effective TRL 1–3 public support requires a tolerance for some level of failure across a portfolio of projects, as it is a natural outcome of a functioning innovation program. Another central piece of feedback was the need for speedy decision-making on grant applications and disbursements to be competitive.

3.2 Considerations for Policymakers

The types of instruments deployed at TRL 1–3 generally do not involve repayment or come with significant repayment risk. At this stage, the primary objective of government financing programs should be long-term strategic direction rather than financial return on individual investments.

Grants have the benefit of being deployable to a range of organization types. For example, a grant can be awarded to a nonprofit (unlike equity), to a venture or project entity with no line of sight to cashflows (unlike a loan), or to a scientific project with no prospect of repayment (unlike equity or a loan). This allows for the kind of technological agnosticism that is important for a successful national R&D program. While grants can require administrative resources for running solicitation, merit reviews, and monitoring compliance, they require a relatively lighter touch than other forms of direct financing, such as loans.

Roundtable participants noted that grants have a significant fiscal burden and do not provide a strong foundation for a longer-term public-private relationship, given they are a one-off payment. Moreover, their nonrecoverability makes grants politically vulnerable during budget cycles, creating uncertainty for multiyear programs. Contingent or recoverable grants—which convert into loans if certain conditions are met—can be considered part of the policy tool kit as well, particularly for technologies that straddle TRL stages. For example, enhanced or closed-loop geothermal drilling in new resource areas may involve TRL 1–3 drilling risk. A government could offer a grant for drilling, which then converts into a loan if geothermal resources are found. This type of instrument can reduce the binary risk associated with large upfront capital investments without oversubsidizing recipients, which supports durability through political cycles.

A direct government equity investment at TRL 1–3 can provide the government with early control over the direction of a recipient's technology or project development. It can also support fiscal considerations around sharing in the upside of public investments. The decision whether to hold an active or passive equity position has important consequences. An active equity investment allows for greater control over decision-making through board participation, voting rights, veto powers, etc. This may be particularly relevant for strategic technologies or projects or in situations that involve highly sensitive intellectual property. A passive equity investment involves less participation in decision-making. Playing either an active or passive equity role is, however, administratively onerous, which limits its reach as a government program to support TRL 1–3 technologies and projects.

3.3 Examples of Government Funding at TRL 1–3

R&D Grants

The Nuclear Energy University Program (NEUP) is run out of the US Department of Energy's (DOE) Office of Nuclear Energy. NEUP funds research, equipment, and education related to conventional and advanced nuclear science and technology.[4] The program issued over $44 million in grant funding to 25 universities in 2024.[5] Selected projects focused on innovation for civil nuclear technologies, including research on advanced manufacturing technologies, fuel performance, safety, modelling, and waste management.

The program funded a portfolio of projects across multiple technical pathways, reflecting tolerance for failure and technological agnosticism. The absence of repayment obligations allowed researchers to pursue iterative, exploratory work without the pressure of financial return.

Innovation Hubs

The Batteries and Energy Storage Hubs[6] are part of the DOE's Energy Innovation Hubs program managed by the Office of Science. The program involves large, multidisciplinary research teams focused on next-generation energy storage technologies beyond conventional lithium-ion chemistries. Established in 2024, the initiative involves two hubs: the Aqueous Battery Consortium led by Stanford University, which focuses on water-based electrolytes, and the Energy Storage Research Alliance led by Argonne National Laboratory, which focuses on long-duration batteries.

The research within these hubs is conducted through a collaborative partnership model rather than through one-off grants. The DOE provides funding directly to the lead institutions, which then distribute the funds to a preselected integrated team of experts from numerous partner universities and national laboratories to perform the research work. The funding relationship between DOE and the lead institutions reduces the administrative burden on the DOE while ensuring that the research program has clear direction. The longer-term partnership model also allows the government to have sustained engagement with and influence over the program.

Grants Followed by Cost-Sharing Agreements

Sila Nanotechnologies[7] is a battery materials manufacturer that developed a next-generation silicon-based anode as an alternative to graphite. Between 2010 and 2012, Sila received its initial public funding through two federal grants—a $3.2 million grant from the Advanced Research Projects Agency-Energy (ARPA-E) and a $0.5 million grant from the National Science Foundation (NSF). (ARPA-E is an agency within the DOE that funds high-risk energy-related research, and NSF is an independent federal agency that supports scientific research across a range of nonmedical fields.) The grants were used to conduct early-stage development and to meet technical milestones required to raise the next round of funding from private investors. As Sila progressed to TRL 4–7, the company also benefited from support from the Office of Energy Efficiency and Renewable Energy, including national lab testing and materials validation. Sila went on to raise private capital and completed construction of its first manufacturing facility at Moses Lake, Washington, at the end of 2025. To build out this facility, the company received a $100 million cost-sharing agreement from DOE's Office of Manufacturing and Energy Supply Chains and benefited from the Section 45X Advanced Manufacturing Production Credit under the IRA. It also was recently awarded a conditional $1.4 billion loan commitment from the government to expand anode manufacturing and build out a new battery cell manufacturing facility.[8]

The shift from grants and technical assistance to a cost-sharing agreement and then a loan is a good example of how forms of public support transition across TRL stages.

4. TRL 4–7: Public Support as a Bridge to Commercial Viability

Technologies at TRL 4–7 have validated their core scientific principles in lab settings but face the critical "valley of death" of demonstrating meaningful production. The central challenge shifts from technical feasibility risk to demonstration and integration risk (*will it work outside the lab?*), operational and reliability risk (*will it perform durably in real-world conditions?*), and early commercial risk (*will projected costs hold?*). Projects at this stage are often capital intensive relative to the balance sheets of developers and face substantial execution risk.

TRL 4–7 can be the most fragile phase of the innovation-to-commercialization pathway—progressing scientific concepts to a demonstration of commercial viability is challenging. Assuming that there is clear technical feasibility, a technology may still fail to progress past TRL 1–3 because of a lack of the risk-tolerant capital required to support an initial period of poor cost competitiveness and "learning-by-doing" before reaching commercial viability. Participants noted that it is at this stage that China has excelled with generous state support programs that have thrown the net wide and backed many recipients, a strategy that has produced "technology champions" across sectors.

Private capital plays a larger role at TRL 4–7 than at earlier stages but remains constrained. Strategic corporate investors more readily use their balance sheet to support development and venture capital investors typically engage through either equity or equity-like capital (e.g., preferred equity, structured convertible notes, etc.). Commercial bank and institutional lenders, by contrast, generally require performance track records and contractual revenue certainty that are not yet available at TRL 4–7. This said, some pockets of high-yield structured capital within institutional lender groups may engage toward TRL 7 if there is a line of sight to bankable cash flows. As a result, participants noted that projects at this stage typically draw on several established financing silos, as well as more tailored forms of capital (e.g., structured loans with interest rate grace periods and amortization flexibility as opposed to vanilla bank loans).

Select TRL 4–7 Examples

- **Nuclear:** A number of small modular reactor projects are in the demonstration or construction phase of development and are expected to commence commercial operations by the early- to mid-2030s.
- **Geothermal:** Superhot rock geothermal remains at an early development stage, with several field demonstrations underway but no commercial-scale deployment.

4.1 Perspectives from Project Developers and Investors

Several roundtable participants stressed that the core challenge at TRL 4–7 is structuring public instruments to credibly share and manage FOAK risk alongside private capital. Participants broadly agreed that the public instrument mix at TRL 4–7 can shift away from pure grants toward blended and conditional forms of support that share risk. A cost-sharing agreement can achieve this, with the percentage of cost-sharing varying with the degree of TRL risk.

A recurring theme across both roundtables was the role public agencies can play in providing technical validation and certification. Several participants highlighted that cost-sharing agreements with disbursements tied to clear technical or development milestones were a valuable design feature for mobilizing private capital, particularly for technologies for which there is underdeveloped advisory expertise, such as independent engineers and third-party validators, to inform investor due diligence. In this way, technical validation itself was described as a quasi-instrument in that it sends a de-risking signal to private investors by meeting an information gap surrounding the feasibility of the technology.

Participants noted that clarity on cost-sharing agreement provisions that may require repayment or transfer of title to the government (e.g., due to infringements on terms related to intellectual property or change of ownership) is crucial for crowding in private capital. An example of such a condition is a foreign ownership threshold, beyond which the government retains the right to claim title over the funded assets. Participants noted that even when such provisions address remote scenarios, a lack of detail around these conditions complicates capital raising from private sources, given that investors underwrite to “downside” scenarios.

Participants also highlighted that government equity investments at TRL 4–7 can provide an early demonstration of public commitment to a project and signal confidence to the market, catalyzing private investment in subsequent rounds. For this signaling to be effective, investors again stressed the importance of clarity around control, governance, and exit intentions, given that the government as an investor is not solely driven by financial returns. Late-stage government entry risks raising governance concerns among earlier investors, particularly where the government seeks an active equity role.

4.2 Considerations for Policymakers

The key difference for TRL 4–7 compared with TRL 1–3 is the larger size of the financing requirement but the lower risk profile of the recipient. At this stage, projects can attract private capital, given the clearer line of sight to commercialization.

Compared with a grant, the key advantage of a cost-sharing agreement is incentive alignment between the recipient and the government. Since the recipient must commit a substantial amount of its own capital, it has a greater degree of "skin in the game." Cost-sharing agreements also take advantage of private sector vetting and expertise, unlike grants, which more heavily rely on public sector knowledge. This coselection with the private sector provides the government with additional data points to inform recipient selection, sometimes described as the challenge of "picking winners."

Unlike at TRL 1–3, public support at this stage should start to enforce rather than defer commercial discipline. A key challenge for the government at this middle stage is to support demonstration and development without entirely insulating firms from commercial realities. Overly generous or poorly structured grants can prolong reliance on nonrepayable funding and delay the development of efficient technologies and bankable project structures. Conversely, support that is too limited can prevent recipients from reaching the technical and commercial milestones, such as first prototypes or demonstrated operating track records, that are necessary to attract private capital around TRLs 4 and 5. To strike this balance, cost-sharing agreements can be structured with a sliding-scale cost share. For example, a project at TRL 4 may be well suited to a 50% cost-share requirement, while a project at TRL 7 may be able to fund 70% of costs with private capital.

As discussed above, at TRL 4–7, all forms of government support, whether they take the form of grants, cost-sharing agreements, equity, or other forms, need to be made with attention to how financing terms impact private capital. At TRL 4–7, the choice between an active versus passive investment is critical, given that private equity capital is typically a significant source of financing. As an alternative to direct government equity stakes, convertible notes (debt instruments with the option to convert to equity) may also be a useful instrument for earlier-stage technologies and projects where valuation is difficult to establish and where downside protection is attractive.

A key consideration for policymakers across these instruments is the trade-off between tailored, high-touch forms of support (e.g., active government equity stakes) and more standardized forms of support (e.g., cost-sharing agreements without technical validation). Bespoke structuring may be necessary at TRL 4–7 given the larger check sizes, but this limits the number of projects a program can support.

4.3 Examples of Government Funding at TRL 4–7

Cost-Sharing Agreement

In 2020 the DOE Advanced Reactor Demonstration Program authorized a 50/50 cost-sharing agreement with TerraPower for the build-out of the company's FOAK Natrium project in Wyoming.[9] The Natrium project uses a sodium-cooled fast reactor and a molten-salt-based energy storage system that allows it to ramp up output during peak demand.[10] Under the agreement, the government matches TerraPower's investment on a dollar-for-dollar basis up to $2 billion. In the first half of 2026, the construction permit was approved, and full construction commenced on the project.[11] While this is FOAK, it should be recognized that it will deliver commercial scale power (at more than 345 megawatts).

The Natrium reactor concept had strong laboratory technical foundations, but financing the full-scale demonstration project with private capital only was challenging given the FOAK risk and the large size of the funding requirement. Government support can play a particularly important role when a funding need is large and highly concentrated in a single early-stage asset.

Concessional Loan

In 2025 the DOE Loan Programs Office issued a conditional loan commitment of up to $1.36 billion to EnergySource Minerals' ATLiS project, a commercial-scale lithium hydroxide facility in California's Salton Sea region that uses direct lithium extraction (DLE) from geothermal brines.[12] The DLE process had been validated at laboratory and pilot scale, and so the project straddled TRLs, with system integration of the TRL 4–7 DLE technology alongside TRL 8–9 processing technology.

This example illustrates how a single project can span multiple TRL stages simultaneously and how the choice of public instrument should be calibrated to the specific dimension of risk being addressed rather than the project's overall commercial maturity.

5. TRL 8–9: Public Instruments to Absorb Scale-Up and Commercial Risk

At TRL 8–9, the dominant challenges involve commercial-scale construction, end-market, regulatory, and geopolitical risks. Projects at this stage are capital intensive and exposed to market competition, and capital providers are highly sensitive to revenue uncertainty. Private capital plays a central role at TRL 8–9, particularly through infrastructure equity funds and project finance lenders. Compared with TRLs 1–3 and 4–7, the composition of financing at TRL 8–9 is often more debt focused, given the line of sight to positive cash flows.

Key challenges at TRL 8–9 include scale-up risk, as projects are being constructed at commercial scale for the first time, as well as market risk from new end markets that do not yet offer bankable offtake contracts. Lenders require cashflow profiles that meet rigid parameters, including some range of price and volume certainty, which can be achieved with offtake contracts and/or policy measures. In this context, at TRL 8–9, public support remains important, but its role expands from balance-sheet risk absorption to engaging with the specific investment parameters of project finance lenders.

Concessional loans and loan guarantees are useful instruments for TRL 8–9 projects. These tools are particularly relevant for large-scale projects that are highly capital intensive and face market dynamics that are evolving and challenging to forecast. In these situations, it may not make sense for the government to provide revenue stabilization support but rather to act as a direct lender or borrower guarantor—this is especially the case for projects that have national importance for which the government does not want to rely on the availability of private capital to get the project off the ground.

In many cases, revenue stabilization instruments will be more appropriate than direct balance-sheet risk absorption for TRL 8–9 projects. Feed-in tariffs, contracts for difference, price floors, and other pricing supports can attract project finance lenders by reducing exposure to market volatility. Long-term government offtake arrangements, government procurement, and coordinated buyer groups can also support project bankability by providing volume certainty for nascent markets.

Measures such as tax credits, accelerated depreciation, and royalty reductions are also core instruments at TRL 8–9. Roundtable participants noted that these instruments are best suited to projects and technologies that have established contractual structures and end markets but involve some degree of cost competitiveness or operational risk.

Other risk-mitigation instruments, including political risk insurance, completion guarantees, and foreign-exchange hedging, can also be important for cross-border projects and those with geopolitically exposed supply chains.

Select TRL 8–9 Examples

- **Mineral extraction and processing:** Conventional mineral extraction processes (e.g., open pit and underground for copper or hard rock mining and brine evaporation for lithium) are mature processes and technologies at a global level yet face volatile end markets.
- **Battery manufacturing:** Lithium iron phosphate (LFP) batteries are technologically mature and widely deployed, with performance characteristics sufficient for most electronic vehicle (EV) and stationary storage applications. Despite this technological maturity, LFP manufacturing in the US faces severe structural competitiveness challenges relative to China.
- **Wind and solar:** Mainstream onshore wind projects, fixed-bottom offshore wind, and conventional utility-scale solar PV fall within the TRL 9 bucket in the US. These are mature, rapidly growing technologies with well-established development, performance, and capital efficiency benchmarks. Government support for wind and solar in the US is more focused on accelerating deployment and meeting other industrial policy goals (e.g., domestic content) rather than absorbing technology risk.

5.1 Perspectives from Project Developers and Investors

Roundtable participants consistently stressed that providing some level of revenue certainty at TRL 8–9 can be highly effective at mobilizing private capital. Several noted that even price stabilization mechanisms that mitigate against remote downside scenarios can unlock significant project finance.

Roundtable participants highlighted the complexities that arise from direct government support at this stage, such as when the government is lending alongside other senior lenders or when the government is providing a loan guarantee. Clear contractual terms around enforcement mechanics and loss-sharing arrangements in case of default must be in place. Investors also cautioned that if government equity participation is intended for TRL 8–9, and the company is publicly listed, sensitivity to public market messaging on the nature of the government's equity role (e.g., whether it is an active or passive stake) is important to support future capital raises.

Project developers said a major challenge for them at TRL 8–9 is construction cost uncertainty, particularly for large-scale projects and for sectors where construction supply chains are evolving. Lenders may demand large construction cost overrun reserve accounts that are not feasible. Participants noted that governments can support projects at this stage by offering risk-specific or contingent facilities, which are drawn on only if specific risks are realized. In addition to cost overruns, other types of contingent risks that may be well suited to these kinds of facilities include regulatory and supply chain risks. These are largely out of the project developers' control and are not insurable.

Participants broadly noted the importance of tax credit transferability for supporting project financing. In a tax credit transfer market, an entity can sell its future expected stream of tax credits to another entity. The tax credit seller typically lacks sufficient tax liability, at least in the near term, and so cannot take full advantage of the credits. The tax-credit-generating project receives an upfront payment in exchange for the sale, which is typically used for debt paydown or for general liquidity. (Historically, in the US, this transfer of tax benefit has been through the more complex tax equity structure. The IRA simplified this through the introduction of tax credit transferability.)[13]

Key barriers to financing at TRL 8–9 also include regulatory uncertainty and permitting delays. In several cases discussed at the roundtables, these risks were more binding than some degree of technology risk. Even in the case of projects with robust returns, participants noted that long permitting lead times and regulatory uncertainty can shift investor interest to alternative opportunities with lower returns but clearer regulatory pathways.

5.2 Considerations for Policymakers

A key instrument for direct financing support at TRL 8–9 is concessional loans. Customizable features in a loan (e.g., interest rate, amortization, covenants, collateral, etc.) allow the government to tailor loan terms to the specific risks and characteristics of the project recipient. Loan terms can be structured to support the sensitivities of private capital while ensuring downside protection for the government. For example, roundtable participants noted that project finance lenders are typically sensitive to large outstanding balances of principal (also known as "balloons") at a loan's maturity, as this exposes the project finance lender to refinancing risk. In this context, a government loan may have a slower repayment schedule than that of other senior lenders to a project, but the government would maintain an equal claim on collateral in case of default.

Later-stage policy interventions are well suited to target market design. Revenue stabilization tools such as contracts for difference and forward contracts provide a level of certainty on a project's future cash flow, with the amount of government outlay dependent on the degree of price variation. This may make them more fiscally attractive compared with other forms of direct support, such as loans, assuming they have adequate collateral or other security requirements.

The design of some revenue stabilization instruments requires a nuanced understanding of market conditions. Market volatility can make it challenging to forecast their full fiscal impact in downturn scenarios. While not always the case, contracts for difference typically have price levels set through an auction process and so rely on market forces for initial price discovery. This contrasts to feed-in tariffs and other price stabilization mechanisms that require government analysis and forecasting to determine price levels. Sunset provisions such as built-in timelines for reviewing the price agreed to in the contract can protect the government in market situations that are challenging to forecast. Moreover, in contrast to other measures to support offtake, such as government procurement, which requires actual purchase and ownership, revenue stabilization instruments are strictly financial agreements, which reduce their administrative complexity. Policymakers can also play a dual role designing price stabilization instruments by supporting the development of new price benchmarks. This is particularly relevant for sectors such as hydrogen that face coordination problems around establishing industry-wide standardized contract pricing.

Policy tools such as government procurement, advanced market commitments, and demand pooling can support the development of end markets and be customized to align with other government industrial policy goals (e.g., stockpiling for critical minerals). However, these forms of support require significant administrative resources and are limited in their scalability.

Tax credits are standardized and therefore scalable. Given the nearer line of sight to taxable income, they are well suited to projects and technologies at the higher end of the TRL spectrum. Production tax credits reward actual production but come with uncertainty about their fiscal impact on governments. Investment tax credits are decoupled from production but provide relatively greater certainty about the fiscal impact. Because the government remains at arm's length from the recipient, tax credits are less suited to projects of national strategic importance for which the government seeks a more engaged relationship.

5.3 Examples of Government Funding at TRL 8–9

Contracts for Difference

Contracts for difference (CfDs) are a key policy instrument that the UK uses to support renewable energy generation.[14] CfDs are auctioned to renewable energy suppliers who compete on price for contracts to set the CfD strike price. The UK held seven allocation rounds from 2014 to 2025. The National Energy System Operator runs the allocation rounds, while the Low Carbon Contracts Company, a quasi-government agency, issues and manages the contracts. Under the CfD program, developers receive or pay the difference between the strike price and reference price (average market price for electricity) over a 15-year period.

Tax Incentives

The US IRA included the Section 45X Advanced Manufacturing Production Credit[15] for solar energy components, wind energy components, battery components, inverters, and critical minerals. These production tax credits (PTCs) come with specific qualifying conditions, have various calculations of the PTC value for each product, and have strict phaseout timelines. For example, battery cells are eligible for a credit of $35 multiplied by the maximum kilowatt-hour capacity of the cell and have phaseout timelines, while critical mineral processing projects are eligible for credits equal to 10 percent of the production costs and are not subject to phaseout timelines. The One Big Beautiful Bill Act (OBBBA) accelerated phaseout timelines for wind and solar projects, tightened domestic content requirements, and restricted credit eligibility for projects with links to "foreign entities of concern."

Concessional Loan

The DOE announced a $996 million loan for Ioneer's Rhyolite Ridge project in 2025[16] for the construction of a facility in Nevada to process lithium carbonate. The loan has a 20-year term with an interest rate equal to the US Treasury rate. The project is intended to support the production of lithium for more than 370,000 EVs each year. While the project broadly utilizes conventional mining techniques, there are elements of innovation in the mining and processing methods that are tailored to its unique lithium-boron volcanic ash deposit. The project faces a volatile lithium minerals market, as is characteristic for critical minerals projects at TRL 8–9.

Ioneer is both a strategically important asset for the federal government and faces a buyer market that does not yet offer the "gold standard" in project finance of fixed price and fixed volume offtake contracts. These dynamics, along with the project requiring a large amount of capital, made a direct loan an appropriate form of public support.

6. Conditionality

Governments can embed conditionality into financing tools to align them with other policy objectives, such as social, political, or geopolitical goals. Examples include local content requirements, labor standards, contributions to local communities, restrictions on the destination of the product,[17] and foreign entity restrictions for construction counterparties. Structuring this embedded conditionality can take place through eligibility requirements or price/ quantity adjustments.

Eligibility requirements: Access to government financing can be conditional on meeting minimum eligibility requirements; for example, access to some IRA financing programs required meeting prevailing wage and labor standards. Submission of a Community Benefits Plan, which outlines a project's contribution to the local community, was also an important part of access to loans and grants from the DOE under the IRA. Eligibility requirements can instead impose restrictions on recipients, such as on the origin of construction, supply, and offtake counterparties and the origin of asset purchasers in a change of control event. Foreign entity of concern provisions under the IRA, which were extended and tightened under the OBBBA, are an example of this. Restrictions may also relate to financial management, such as restrictions on stock buybacks.[18]

Price or quantity adjustments: The size and terms of government programs can be adjusted based on meeting different policy objectives, allowing conditionality to be graduated rather than binary. For example, the IRA's tax credits involved "bonus adders" for domestic content minimums and for projects located in low-income or former "energy" communities. Or a loan may have interest rate step-ups subject to certain conditions not being met.

Embedding conditionality in financing tools can build political legitimacy and align projects with broader industrial policy goals, but excessive or poorly designed conditionality can also make financing tools unusable or politically polarizing. Conditional financing tools are ideally just one part of holistic government policy programs that target the full breadth of challenges involved in developing a new clean energy sector, including workforce development, labor protections, construction of critical infrastructure, and geopolitical arrangements to support the development of supply chains. Financing tools can support advancement, but roundtable participants cautioned that progress on these broader social challenges should also be determined by direct, dedicated government policy rather than solely through tweaks to financing tools, whose primary purpose is solving capital access challenges.

7. Sector Clusters: TRLs Across Technologies

In this section, the authors break down five technology sector clusters into the three TRL stages to provide current examples of where different technologies sit along the TRL spectrum. Then, based on roundtable insights, the authors consider how current challenges may be innovatively addressed with government instruments. While not attempting to provide an exhaustive list of relevant policy tools, it highlights several newer ideas that could be relevant to policy makers. This discussion is based on the US context but will likely be relevant to other developed countries.

7.1 Mineral Extraction and Processing

TRL 1–3: High-temperature plasma separation for rare earth elements ("REE") is an early-stage processing technology that is undergoing fundamental research in laboratories. The technology has not been demonstrated at a pilot scale, and no continuous or operational industrial systems exist. Given the technology's nascency, REE plasma separation lacks a commercial supply chain, experienced operators, a workforce, and understanding of cost and performance. At this stage, instruments that share in the cost burden of proof-of-concept research, such as R&D grants and equity investments, are most relevant, as are policies that provide some level of certainty about future demand.

TRL 4–7: New mineral extraction technologies such as direct lithium extraction (DLE) fall under TRL 4–7 in the US. While individual DLE processes have been validated in laboratory and pilot settings, their cost and performance at scale remain uncertain and highly dependent on site-specific brine chemistry. Several FOAK and early commercial demonstration projects are underway. For example, the South West Arkansas project, supported through a grant by the DOE in 2024, is the world's first commercial-scale DLE facility.[19] Projects such as these must demonstrate sustained recovery rates, operating stability, and cost performance to attract follow-on private capital. Government support such as milestone-based cost-sharing agreements, completion guarantees, price floors, and offtake arrangements can be critical at this stage to mitigate early execution and market risk.

TRL 8–9: Conventional mineral extraction processes (e.g., open pit and underground for copper or hard rock mining and brine evaporation for lithium) are mature processes yet face volatile end markets. Project development in the US has slowed over the last few decades because of hurdles such as permitting, litigation risk, regulatory uncertainty, and exposure to global price volatility. At this stage, instruments such as loans, loan guarantees, revenue stabilization mechanisms, and long-term offtake agreements are appropriate. Targeted tax benefits may also provide support, but given that the US already has a low and favorable tax regime for mining compared with most other advanced economies, marginal changes in the tax regime may be less effective for driving new projects.

Innovative Instrument Ideas for Minerals Extraction and Processing

Key challenge (TRL 1–3)

Early-stage mineral processing technology faces uncertainty around what the critical mineral offtake market will look like once the project transitions to TRL 4–7 and 8–9. An instrument that helps bridge this uncertainty between TRL 1–3 and 4–7 would support early-stage development.

Instrument: Advance market commitments conditioned on achieving defined technical performance milestones (e.g., purity, recovery). This would provide an early line of sight to offtake, helping de-risk R&D while not compromising on technical and quality standards.

Key challenge (TRL 4–7 and 8–9)

Mineral processing technologies such as DLE are technically validated but face uncertainty around a facility's ability to produce reliable volumes at scale during the ramp-up period.

Instrument: Government reserve account to backstop existing debt service reserve account for a defined period during early production. The account can be drawn on if the production rate is insufficient to maintain appropriate levels of cash flow (e.g., triggering minimum-debt servicing covenants). A government reserve account is "contingent," in that it can only be drawn on if the project meets an agreed threshold of product purity to battery-grade specification. That is, the reserve account targets shortfalls in volume rather than processing quality.

Key challenge (4–7 and 8–9)

Early-stage mineral processing projects are equipment intensive, which is a significant contributor to total project costs. Equipment can be reused for other projects if an individual project or company fails.

Instrument: Asset-backed equipment finance for minerals processing and refining facilities to provide publicly backed, collateralized loans for furnaces, acid plants, and by-product recovery equipment. Recoverability of assets limits public downside.

Key challenge (8–9)

Mineral smelters face significant international competition because of cost fundamentals and overcapacity in other economies. Treatment and refining charges are the main revenue components for refining facilities, but in several critical minerals markets, they are insufficient to cover refining costs.

Instrument: Backstop floor price contracts for treatment and refining charges for strategically important mineral smelters to provide some cash flow certainty.

Key challenge (8–9)

New critical mineral and rare earth projects face unsteady offtake markets, which limit the availability of project financing and increase the cost of capital. For example, long-term offtake contracts with fixed price and volumes can be challenging to secure for lithium as well as strategic minerals such as rare earths, geranium, and gallium.

Instrument: Governments as buyers of last resort with price-floored and fixed-volume contracts that are activated if certain conditions are met. Conditions may include a company undertaking specified efforts on sales and marketing, such as obtaining two to three memoranda of understanding with potential offtakers.

7.2 Battery Manufacturing

TRL 1–3: Next-generation solid-state and semisolid battery technologies largely remain in early TRL stages in the US. Core challenges are concentrated in proving the materials science, manufacturability, and long-cycle durability. Much of the work is at proof-of-concept and laboratory validation stages, including research at Oak Ridge National Laboratory on solid-state electrolyte properties.[20] These technologies would benefit from R&D grants and continued direct public research to validate fundamental performance and manufacturability.

TRL 4–7: Early commercial demonstrations and FOAK projects are underway in the US to validate the performance, cost, and manufacturability at scale of advanced battery chemistries such as sodium ion or lithium sulfur. Several domestic manufacturing milestones were announced in 2024 in this space, such as a FOAK sodium-ion battery manufacturing facility in Michigan[21] and over 90 percent yield benchmarks being established at a lithium-sulfur battery facility in California.[22] At this stage, projects benefit most from equity investments, cost-sharing agreements, and loan guarantees, as well as tools that stabilize cash flows, such as offtake agreements, demand pooling, or advanced market commitments.

TRL 8–9: Lithium iron phosphate (LFP) batteries are technologically mature and widely deployed globally, with performance sufficient for most EV and stationary storage applications. Despite this technological maturity, LFP manufacturing in the US faces structural competitiveness challenges relative to China, and so government support remains crucial for building out the sector. This was made clear when several planned battery manufacturing and materials projects (including LFP-related facilities) were delayed or canceled following shifts in federal support.[23] Commercial viability at TRL 8–9 remains highly sensitive to policy conditions that enhance LFP manufacturing cost competitiveness and ensure adequate demand.

Innovative Instrument Ideas for Battery Manufacturing

Key challenge (TRL 1–3)

Early-stage battery technology developers face the challenge of uncertain future battery market conditions; for example, the commerciality of some highly specific battery chemistries is not always clear at TRL 1–3. An instrument that helps bridge this uncertainty between TRL 1–3 and 8–9 would support early-stage development.

Instrument: Advance market or nonbinding demand commitments conditioned on lab-validated cells meeting predefined metrics (e.g., cycle life, safety, fast charge). This would provide an early line of sight to offtake with the right R&D incentives in place.

Key challenge (TRL 4–7 and 8–9)

Battery technology facilities face the challenge of significant periods of battery qualification and testing from offtakers. Long ramp-up periods can extend the grace period on the project finance loan during which amortization is deferred and interest is paid out of an interest-during-construction reserve account. Large interest-during-construction reserve accounts can put pressure on total financing size.

Instrument: Publicly funded or subsidized interest-during-construction reserve accounts to support uncertainty in the qualification period.

Instrument: Qualification is also a process requiring human capital, particularly skilled engineers. Public cofunding of qualification engineers could reduce qualification timelines.

Key challenge (TRL 4–7 and 8–9)

Even after passing initial qualification, FOAK battery facilities face higher risk around meeting contractual specifications (e.g., degradation, availability) in the initial operating period. This can mean that there is an initial period of offtake volume uncertainty even once the offtaker has started purchasing the product.

Instrument: Time-limited performance insurance for FOAK battery systems and new factories. Publicly supported coverage for a fixed period that compensates lenders if there is some delay or issue with offtakers purchasing the product because of buyer-specific contractual stipulations.

Key challenge (TRL 4–7 and 8–9)

Early-stage battery technology projects are equipment intensive, which contributes significantly to total project costs. Equipment can be reused for other projects if a project fails.

Instrument: Asset-backed equipment finance for battery manufacturing to provide publicly backed, collateralized loans for high-value manufacturing equipment (e.g., coating, calendering, formation lines). Recoverability of assets limits public downside.

Key challenge (TRL 8–9)

Given China's dominance in LFP and NMC battery chemistries, governments may want to provide incentives to support new types of battery chemistries.

Instrument: Production tax credits for new domestic battery production can be complemented with "adders" for specific new battery chemistries.

7.3 Wind and Solar

TRL 1–3: Advanced wind turbine designs that improve the performance and durability of wind power plants are at TRL 1–3. In solar, new concepts such as perovskite or tandem cell science focused on improving efficiency and stability at the cell and minimodule level are also early stage. These technologies are still at the proof-of-concept stage, with performance benchmarks being established before being integrated into demonstrations and pilot projects. At this stage, R&D grants, equity, and government research—such as that being conducted by the National Laboratory of the Rockies on perovskite cell science[24]—can support further development of these technologies.

TRL 4–7: The engineering for floating offshore wind projects is validated, but the bankability of FOAK projects face challenges around complex installation procedures, associated high costs, and uncertain regulations.[25] While there are currently no floating wind projects in the US, the Pacific Northwest National Laboratory and related DOE research entities are actively investigating the potential to deploy projects on the West Coast.[26] These projects would benefit from concessional loans given the high capital costs and revenue stabilization tools to reduce exposure to volatility in electricity prices.

TRL 8–9: Mainstream onshore wind projects and conventional utility-scale solar PV fall within the TRL 8–9 bucket in the US. These are mature, rapidly growing technologies with well-established development, performance, and capital efficiency benchmarks. At this stage, government support is less about bridging technology risk and more about improving project economics to accelerate deployment at scale. Instruments to achieve this can include revenue-stabilizing and revenue-enhancement tools such as government power purchase agreements, CfDs, tax credits, and capacity auctions, as well as grid integration and transmission support. It is important to note that depending on the specific sector, some revenue-stabilizing instruments could become very expensive in light of competition from China. In other cases, they are no longer necessary as technologies become competitive.

Innovative Instrument Ideas for Wind and Solar

Key challenge (TRL 4–7)

Insurance contracts for TRL 4–7 projects such as floating offshore wind are often expensive or unavailable because private insurers lack sufficient historical data on similar projects to be able to price the insurance competitively.

Instrument: Create a time-limited public reinsurance facility that backstops some predefined technology and installation risks specific to offshore wind projects (e.g., moorings, dynamic cables, tow-out/installation failures) for FOAK projects. The facility is not supposed to be a replacement for private insurers, but mitigating tail risks through the reinsurance facility will allow private insurers to underwrite with lower premiums. This will improve the ability of projects to secure financing by incentivizing investors to lower contingency reserves and risk premiums.

Key challenge (TRL 8–9)

Conventional wind and solar projects often have to wait years to come online because of interconnection delays driven by utilities needing to upgrade transmission infrastructure to be able to accommodate the new power plant.

Instrument: Provide standardized terms for generators to enter provisional interconnection sooner with a mandatory curtailment (i.e., utility-directed limits on how much power a generator may deliver to the grid) regime until the utility has completed necessary transmission upgrades. Because curtailment will present challenges for financial viability, this can be paired with a public curtailment insurance guarantee to ensure that the project has sufficient cash flow to maintain compliance with loan covenants during the provisional period.

7.4 Geothermal

TRL 4–7: Superhot rock geothermal remains at an early development stage, with several field demonstrations underway but no commercial-scale deployment in the US. While the underlying geothermal resource is relatively well understood, the primary bottleneck to commercialization lies in developing ultradurable tubulars and casings capable of withstanding extreme thermal and pressure conditions. At this stage, targeted public R&D grants and dedicated testbeds in high-geothermal potential regions can help resolve key technical uncertainties and accelerate commercial viability.

TRL 4–7: Enhanced and closed-loop geothermal systems are progressing through advanced demonstration phases, with multiple pilot and early commercial projects underway (with the latter moving toward TRL 8), though sustained utility-scale operation is yet to be widely proven. At this stage, milestone-based cost-sharing agreements can attract private capital while providing structured technical validation. Measures to de-risk drilling, particularly for FOAK deployments where subsurface uncertainty and elevated drilling costs materially affect project economics, are also important.

TRL 8–9: Although drilling costs are expected to decline, exploration and early drilling expenditures will remain elevated in the near term. Government loans provided before the financial investment decision can help absorb early-stage resource risk. This is particularly relevant absent well-defined, collateralizable reserves such as those that exist with oil and gas. Investment tax credits may further support project economics, given the sector's high capital intensity. While geothermal projects ultimately sell into domestic electricity markets and can secure long-term offtake agreements, their levelized cost of electricity is likely to remain high in the medium term. As such, joint utility and corporate mechanisms such as "clean firm" tariffs (being developed by corporate buyers such as Google in partnership with utilities in Nevada) are also ways to support the sector.[27]

Innovative Instrument Ideas for Geothermal

Key challenge (TRL 1–3)

Early-stage geothermal innovation is constrained by limited access to suitable high-enthalpy sites and insufficient shared subsurface data, which means individual firms face high costs and geological uncertainty when attempting FOAK drilling experiments.

Instrument: Public geothermal testbeds providing low- or no-cost access to land and shared infrastructure for universities and firms to trial novel drilling techniques and reservoir approaches. By concentrating experimentation in well-characterized subsurface environments and openly sharing nonproprietary geological data, testbeds could accelerate technology validation and support the ability of early-stage technology to secure financing.

Key Challenge (TRL 4–7)

Geothermal projects have low-to-no immediate taxable income, and so potential tax deductions cannot be monetized by project developers despite high upfront exploration costs.

Instrument: A pass-through tax mechanism allowing geothermal developers to transfer tax deductions for exploration and drilling expenses to investors could crowd in early risk capital for drilling and subsurface validation (similar to Canada's flow-through sharing for mining).

7.5 Nuclear (SMRs and Conventional Reactors)

TRL 1–3: Several nuclear technologies are still in the proof-of-concept stage in the US, such as direct internal recycling for nuclear fusion.[28] At this stage, government initiatives that help facilitate R&D, such as equity and grants, can be appropriate. Research conducted by the DOE national laboratories can also help further this technology's development.

TRL 4–7: A number of small modular reactor (SMR) projects are in the demonstration, advanced preconstruction, and now construction phase in the US and are expected to commence commercial operations by the early- to mid-2030s.[29] China and Russia are the only countries with operational SMRs,[30] with competing underlying technologies. At the current development stage in the US, SMRs would benefit from government equity, grants, cost-sharing agreements, and convertible notes.

TRL 8–9: Conventional large light water reactors have been commercial in the US since 1957 and have generated roughly 18–20% of US electricity since 1990.[31] There are 54 operating plants (94 reactors) in the US, with most built between 1970 and 1990.[32] Projects such as Watts Bar Unit 2 and Vogtle Units 3 and 4 have come online more recently and face substantial execution and project delivery issues.[33] At this stage, government financing instruments that can help absorb high project costs such as loans, loan guarantees, contingent risk support, and completion guarantees are useful.

Innovative Instrument Ideas for Nuclear

Key challenge (TRL 1–3)

Early-stage nuclear technologies, such as direct internal recycling for fusion, are too far from commercial deployment to attract private risk capital, and progress depends heavily on sustained public R&D and national lab capacity.

Instrument: Continued government equity and milestone-based grants channeled through DOE's Office of Nuclear Energy and the national labs, paired with structured public-private cost-share arrangements as concepts mature toward demonstration.

Key Challenge (TRL 4–7)

Multiple SMR designs are advancing toward construction, but the first unit of each design carries disproportionate cost and schedule risk before the design has been replicated, and private lenders and insurers have little data to price that risk.

Instrument: Milestone-based cost-sharing agreements and equity tied to construction progress, complemented by contingent government financing that activates above an agreed cost or schedule threshold.

Key challenge (TRL 8–9)

Delays and cost overruns on projects like Vogtle Units 3 and 4 reflect the elevated risk of building the second and third copies of a reactor design, before the industry has rebuilt construction experience and supply chains. This is a gap that developers, owners, and EPC (engineering, procurement, and construction) contractors are not well positioned to absorb alone.

Instrument: Government financing structured to explicitly share second- and third-of-a-kind construction risk (for example, cost-overrun backstops or contingent financing above an agreed threshold) potentially paired with data-sharing requirements so later projects benefit from lessons learned on earlier ones. Support could taper as a design moves further along its own build sequence and replication risk declines.

8. Making Policies Durable and Effective

In addition to the nuts and bolts of financing instruments, discussion across both roundtables focused on challenges related to the political durability and administration of government financing programs.

Political Durability

While much general discussion around the political durability of the IRA has been on the benefits the act accrues to Republican-leaning states, roundtable participants also focused on creating political durability through bureaucratic structure. Participants emphasized that public lending programs should be administered outside of policymaking departments in a way that institutionally separates them as technocratic and "arm's-length" agencies focused on execution rather than policymaking. This may support durability through political cycles.

Participants also stressed the importance of credible narratives about the public value of lending programs and acceptable loss rates. Participants noted that large-scale support for individual firms increasingly attracts public scrutiny, particularly where benefits appear concentrated or are poorly explained. Programs perceived as favoring specific firms and instruments that are opaque can be politically fragile and require clear government messaging on public value. The memory of Solyndra, a solar panel manufacturing company that went bankrupt in 2011 after receiving $535 million in DOE loan guarantees, and its long-term impact on political thinking were noted several times. Participants also discussed the potential for portfolio approaches to government investments, similar to sovereign wealth funds, which could reduce the politicization of individual failed investments.

Administrative Effectiveness

Participants discussed the need, particularly for small- to medium-sized companies, for a single, easily accessible register of available public support, including at the local and state levels. Where there is duplication across public financing programs, clear information on how they overlap and interact would be helpful.

Another key topic of discussion was workforce development and retention in public agencies. Participants noted the challenges of retaining long-term government employees and having the flexibility to recruit from the private sector when needed, even if for shorter periods. Creating productive dynamics between these two pools of talent is important. Participants highlighted that national labs are sometimes government owned but contractor operated, which can support preservation of talent through political cycles.

A central theme across both roundtables was the challenge of navigating the bureaucracy and sometimes slow decision-making in government programs. Participants said these issues represent major obstacles to securing government funding and have material impacts on project timelines and global competitiveness. Some potential means for accelerating funding mentioned by roundtable participants include delegated approval authority for grants below certain dollar thresholds, standardized term sheets, and dedicated fast-track reviews for time-sensitive projects.

Appendix: Definitions for Instrument Families 1–4

Upfront Capital Support

- **Grants:** A sum of money that one entity provides to another without an obligation for repayment.
- **Contingent grants:** A grant that is only repayable subject to certain conditions being met (e.g., resource discovery).
- **Cost-sharing agreement (CSA):** A contract where multiple entities agree to share the costs of developing a project. In this report, a distinction is made between grants and CSAs; however, government grants typically include a minimum cost-sharing requirement. CSAs here are used to refer to arrangements where a significant share of the costs is borne by the recipient.
- **Loan:** A form of debt in which one party (the lender) provides capital to another party (the borrower) with an agreement to repay the principal, usually with interest, over a specified period. Loan terms such as the amortization schedule, interest step-ups, and interest grace periods can be tailored to the project's financial profile.
- **Loan guarantee:** A contractual commitment by a guarantor to repay the borrower's debt obligations in case of the borrower's default.
- **Convertible note:** A debt obligation that can be converted into equity at a later date under predefined conditions.
- **Equity:** An ownership stake in a project or company in exchange for providing capital.

Revenue Enhancements

- **Investment tax credit:** Allows a taxpayer to directly reduce their tax liability by a fixed percentage of the eligible costs of a qualifying investment.
- **Production tax credit:** Allows a taxpayer to directly reduce their tax liability by a fixed dollar amount per unit of production of a qualifying product.
- **Accelerated depreciation:** Allows businesses to deduct a larger portion of an asset's cost in the early years of its useful life and smaller amounts later, thereby reducing taxable income upfront

and improving near-term cash flow.

- **Royalty reduction or holiday:** Concessions that temporarily lower or waive the payments that companies must make to the state for extracting publicly owned resources.

Revenue and Price Stabilization

- **Feed-in tariff:** A policy that guarantees renewable energy producers a fixed price for every unit of electricity they generate and supply to the grid, typically under a long-term contract.
- **Contracts for difference (CfD):** A financial agreement between a buyer and a seller for a specific product. If the market price of the product falls below (rises above) the strike price (agreed in the contract), the buyer (seller) pays the difference to the seller (buyer).
- **Forward contract:** A legally binding agreement between two parties to buy or sell a specific asset at a predetermined price and future date.
- **Advance market commitment:** A pledge to buy or subsidize a certain volume of a product at a specified price, if and when it is produced to agreed standards.

Offtake and Procurement

- **Direct government purchases:** Procurement contract in which the government commits to buying a good or service at a specified price and quantity.
- **Demand aggregation:** Organizational mechanism through which demand from different buyers is pooled through one central buyer to help provide demand certainty and economies of scale.
- **Strategic stockpiling:** The accumulation of goods or materials for future use. Involves storage, maintenance, and monitoring of the stockpile to ensure security and prevent quality degradation.

Notes

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3. The term "contingent facilities" is used in this report to refer to forms of financing support such as reserves or debt facilities that can only be drawn on if very specific risks (that are not typically covered by ordinary project finance style reserves) materialize.
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