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The Road to FOAK

Challenges and Solutions in Financing the Scaling of Climate Innovation

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PLANETech Climate Change Technologies
Node
KPMG

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Arison ESG Center (Environmental, Social, and Governance), the first academic-practical center in Israel dedicated to ESG, established with the support of the Ted Arison Family Foundation, is uniquely positioned at the intersection of research, education of the next generation of business leaders, support for decision-makers, and the advancement of corporate adoption of sustainable business practices.

Arison ESG Center seeks to play a central role in promoting responsible business conduct and supporting policies that integrate economic growth with social well-being and environmental sustainability. In this context, the Center aims to lead the academic and practical discourse in Israel on the integration of environmental, climate, social, and corporate governance considerations into the core strategies and operations of businesses. By doing so, it seeks to enhance long-term shareholder value while also strengthening the broader impact of ESG integration on the economy, the environment, and society. The Center works together with students, alumni, and senior executives to shape a sustainable business culture - one that not only avoids harm but also strives to generate positive impact through business strategies.

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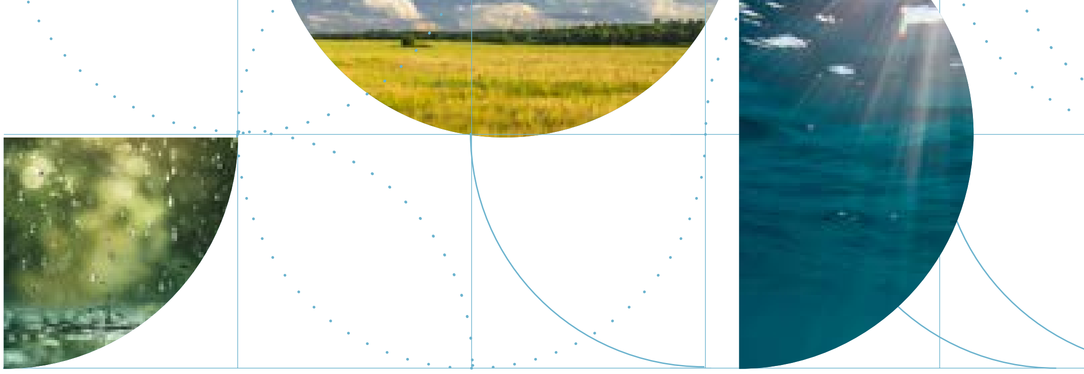


Executive Summary

The FOAK stage is not one challenge among many. It is the most consequential and perilous transition in a climate technology company's lifecycle – and it demands a fundamentally different kind of readiness than the stages that precede it.

The world has the technologies to begin decarbonizing its most emissions-intensive industries. What it lacks is a reliable, well-understood pathway to bring them to commercial scale. **The Road to FOAK** is a comprehensive research initiative dedicated to closing that gap — not by calling for more invention, but by understanding why so many proven innovations fail at the financing and construction of their First-of-a-Kind (FOAK) commercial facility.

This report serves as a **strategic toolkit** for the full climate-tech ecosystem. It offers founders a structured diagnosis of the challenges they will face, most of which can and must be anticipated long before they arrive. It offers investors a granular map of the risk dimensions that determine whether a project succeeds or stalls. And it offers policymakers a systems-level view of the structural mismatches that no single company or fund can resolve on its own. Used together, these components function as an integrated navigation instrument for one of the most complex and consequential journeys in the global effort to address climate change.

The Road to FOAK began as an investigation into a specific question: why do climate-tech startups struggle to raise the capital required to build their FOAK facilities? The answer, emerging from 25 in-depth interviews with founders, investors, policymakers, and project developers, along with a systematic literature review and a structured survey of climate-tech companies and investors, was both more complex and more actionable than expected.

It turned out that financing difficulties are rarely the origin of FOAK failure. They are its final symptom. The decisions that determine whether a company can raise capital, and whether a project, once financed, can survive construction and commissioning, are made years earlier: in technology architecture, pilot design, regulatory strategy, and team composition. By the time a company reaches the financing table, the structural conditions for success or failure have largely already been set.

This realization significantly expanded the scope of the research. Rather than mapping financing challenges alone, the report constructs a comprehensive, granular diagnosis of the full landscape of barriers climate-tech companies encounter on the path to commercial scale—and translates that diagnosis into strategic guidance.

A Comprehensive Map of FOAK Challenges

The challenge mapping at the heart of this report is structured using the U.S. Department of Energy's Adoption Readiness Level (ARL) framework, which organizes barriers into four interconnected risk areas. Each is broken down to its most granular dimensions, enabling companies and their partners to identify the specific obstacles most relevant to their technology, sector, and stage.

A. Value Proposition

While climate technologies are at the core of the ambitious goal of global decarbonization, their viability depends on delivering clear, competitive economic value to customers. This section examines whether such technologies can achieve cost parity with incumbents, sustain reliable output under real-world conditions, and manage the organizational and technical challenges of integration at scale.

B. Market Acceptance

While Value Proposition highlights the technological and operational aspects of integrating and selling the technology, market acceptance focuses on the existing market. Even technically superior technologies can stall in markets that are not ready to adopt them. This section maps the risks of nascent demand and the difficulty of securing long-term offtake commitments, limited market size in early regulatory environments, and downstream value chain fragmentation – the synchronization risk between a FOAK facility and the supply and distribution systems it depends on.

C. Resource Maturity

The 'missing middle' in FOAK financing is well-documented, yet the parallel gaps in human capital, feedstock availability, and infrastructure readiness receive far less attention. This section maps both dimensions: the structural mismatch between FOAK risk profiles and existing investor categories, and the operational resource constraints –workforce, supply chain- and materials sourcing, that determine whether capital, once secured, can actually be deployed.

D. License to Operate

As FOAKs develop something new, regulatory systems aren't prepared or structured to work with them, with a sequential approval architecture. In many jurisdictions, environmental impact assessments, land-use authorizations, and safety certifications must be completed one after another. Each stage can trigger additional reviews or appeals. No unified timeline, no lead agency, no consolidated decision structure. This section examines regulatory fragmentation and permitting unpredictability, policy instability, environmental and safety compliance for novel processes, and community perception.

The Climate FOAK Playbook

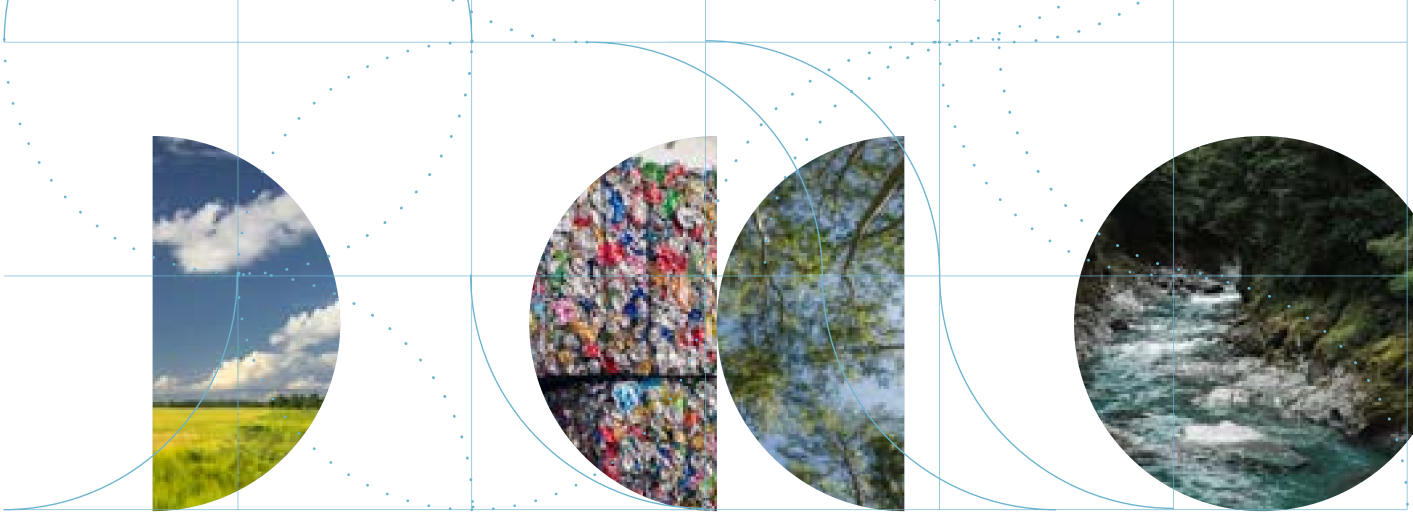
The second major component of the report translates the challenge map into strategic interventions — not a fixed recipe, but a structured framework of choices and trade-offs that companies and ecosystem actors must navigate. It covers the following areas:

For Companies

- Blended Finance – Layered capital architectures that combine public, private, corporate, and impact investment.
- Human Capital – Building teams with industrial-scale project development experience.
- Techno-Economic Analysis – Using TEA from the earliest stages to expose hidden cost liabilities.
- Fast vs. Gradual Scale-Up – Balancing the financial logic of moving fast against the operational logic of gradual de-risking.
- Flexibility vs. Planning Discipline – Front-loading design decisions while preserving strategic flexibility using a design freeze.
- Insurance Readiness – Treating insurability as a design constraint from the pilot stage.
- Policy-Led Strategy – Integrating regulatory and policy analysis into the earliest product and market decisions.

For Governments and Ecosystem Players

- **Human Capital –** Cross-pollinating public finance institutions with venture capital expertise, and private investment teams with industrial project experience.
- **Open-Access Benchmarks –** Creating public databases of FOAK project costs and performance, the single most cited factor among investor respondents when asked what would most increase their confidence in FOAK investments.
- **Governments as Lead Customers –** Using public procurement as a demand-creation mechanism.



The companies that navigate FOAK complexity most successfully do not attempt to build all necessary capabilities in-house. They construct ecosystems of partnerships.

SPOTLIGHTS

The report’s analytical framework is grounded in three extended case studies, each illuminating a distinct dimension of the FOAK challenge.

LanzaTech demonstrates how a capital-light licensing model and proactive regulatory engagement allowed a carbon capture and utilization company to build commercial scale while managing simultaneous technology, market, and regulatory risks.

UBQ Materials illustrates a distinct set of challenges in the waste-to-value space: creating and validating a new material category, building a downstream value chain for a new product, and sustaining the organizational discipline required for a long-horizon commercialization process.

China’s Climate-Tech Ecosystem provides a comparative perspective showing how coordinated national industrial policy, long-horizon capital, and deep supply chain integration can advance climate technologies at a speed and scale that fragmented, market-led approaches have struggled to match.

The EU Industrial Accelerator Act (IAA) signals a new policy environment streamlining permitting and creating "Made in Europe" lead markets. Its mechanisms, such as approval timelines of up to 18 months, directly addresses risks that typically stall climate FOAK commercial facilities.

How to Use This Report

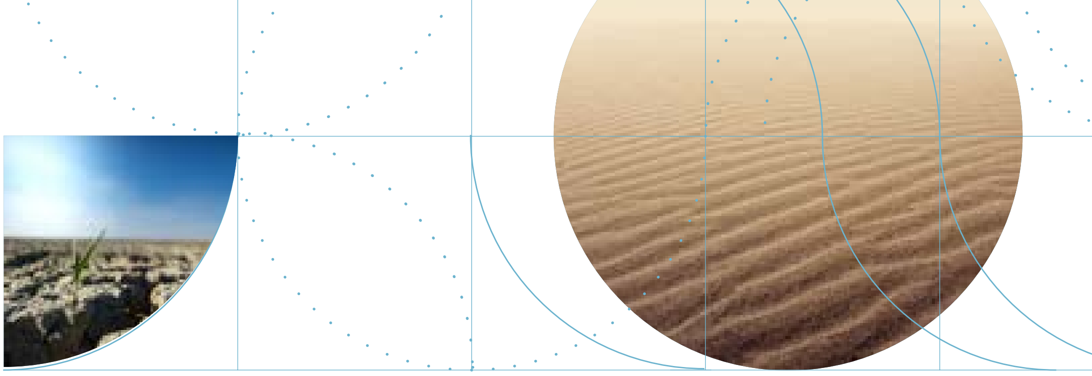
The Road to FOAK is designed to be used, not merely read. Its components serve different purposes depending on where you are situated within the ecosystem.

Founders & Operators	Use the Challenge Map as a self-assessment tool, ideally 12–24 months before the FOAK financing stage begins. Use the Playbook to sequence decisions on financing architecture, team composition, regulatory engagement, and scale-up pacing.
Investors	Use the Challenge Map to structure due diligence beyond financial modeling – assessing organizational readiness, regulatory positioning, and supply chain maturity. Use the blended finance section of the Playbook to identify the right syndicate composition for each stage of the capital stack.
Policymakers	Use the Challenge Map to analyze local barriers that could be tackled using regulation. Focus on the License to Operate section to identify the regulatory bottlenecks that create the most systemic friction, and the Stakeholder Playbook for concrete mechanisms to reduce them.
Corporate Partners	Use the Market Acceptance and Resource Maturity sections to understand where offtake agreements, supply chain integration, and technology validation partnerships create the most decisive de-risking value, and how to structure them for mutual benefit.

A Starting Point, Not a Conclusion

The FOAK landscape is evolving rapidly. The barriers documented here are real, but they are not fixed. Every company that successfully crosses the Valley of Death makes the crossing marginally easier for the next, by validating the investment thesis, establishing regulatory precedent, demonstrating technical feasibility at scale, and building the ecosystem of knowledge, relationships, and institutional capacity that the sector needs.

The Road to FOAK is offered in the spirit in which it was built, as a shared resource for an ecosystem that rises or falls together. The path is difficult. The terrain is mapped here. What remains is the work of navigating it – with the foresight, preparation, and collaboration that this stage demands and that this report is designed to support.



Introduction

Addressing this gap is no longer primarily an R&D challenge where further research yields the greatest environmental impact; it is a commercialization challenge centered on moving existing inventions to a global scale.

The climate technology sector stands at a pivotal crossroads. Decades of scientific progress have produced a generation of breakthrough solutions – in green hydrogen, carbon capture, sustainable fuels, advanced materials, and industrial decarbonization – that are technically proven and commercially promising. Yet an alarming number of these technologies fail to cross the threshold between successful demonstration and full-scale commercial deployment. They stall, or shut down entirely, at the stage known as the Valley of Death of the First-of-a-Kind (FOAK) facility: the first full-scale, commercial-grade instantiation of a novel technology in the real world. This phenomenon should be of great concern, since achieving net zero requires new technologies that work not only in the lab but also in the field and at scale.

The International Energy Agency (IEA) estimates that 35% to 40% of the emission reductions required by 2050 depend on technologies not yet commercially deployed (CREO, 2024; Barclays, 2024). Bridging this gap is proving increasingly difficult. According to Net Zero Insights' State of Climate Tech 2025 Report, only 53.5% of companies successfully transitioned from the demonstration stage to full commercial readiness - a gruelling process that takes an average of 6.11 years. This "commercialization crunch" is worsening; in 2025, only 10.1% of companies at the TRL 7-8 stage achieved readiness, a sharp decline from 18.2% in 2024 (Net Zero Insights, 2025). This slowdown results in fewer viable companies and a dangerous delay in deploying critical climate solutions.

Addressing this gap is no longer primarily an R&D challenge where further research yields the greatest environmental impact; it is a commercialization challenge centered on moving existing inventions to a global scale. Overcoming this hurdle represents a massive opportunity for both environmental transformation and commercial growth. Consequently, our focus is dedicated to helping companies navigate the critical FOAK stage, ensuring breakthrough technologies survive the transition to market.

This report began with a specific, bounded question: why do climate-tech startups struggle to raise the capital required to build their FOAK facilities? We set out to map the financing gap - to understand why the funds dry up and slow down precisely when they are needed most, and to identify what startups, investors, and governments could do differently.

The more we engaged with founders, investors, policymakers, and project developers, through an extensive literature review, in-depth interviews, and structured questionnaires, the clearer it became that framing FOAK failure as a financing problem was both inaccurate and insufficient. Financing is, in many cases, the final symptom of a deeper, more complex set of challenges. A company that cannot raise capital for its FOAK is rarely facing a problem that begins and ends with investors. More often, the financing gap is the visible surface of a much deeper set of structural barriers – some rooted in the broader ecosystem, some in the unique complexity of the FOAK stage itself.

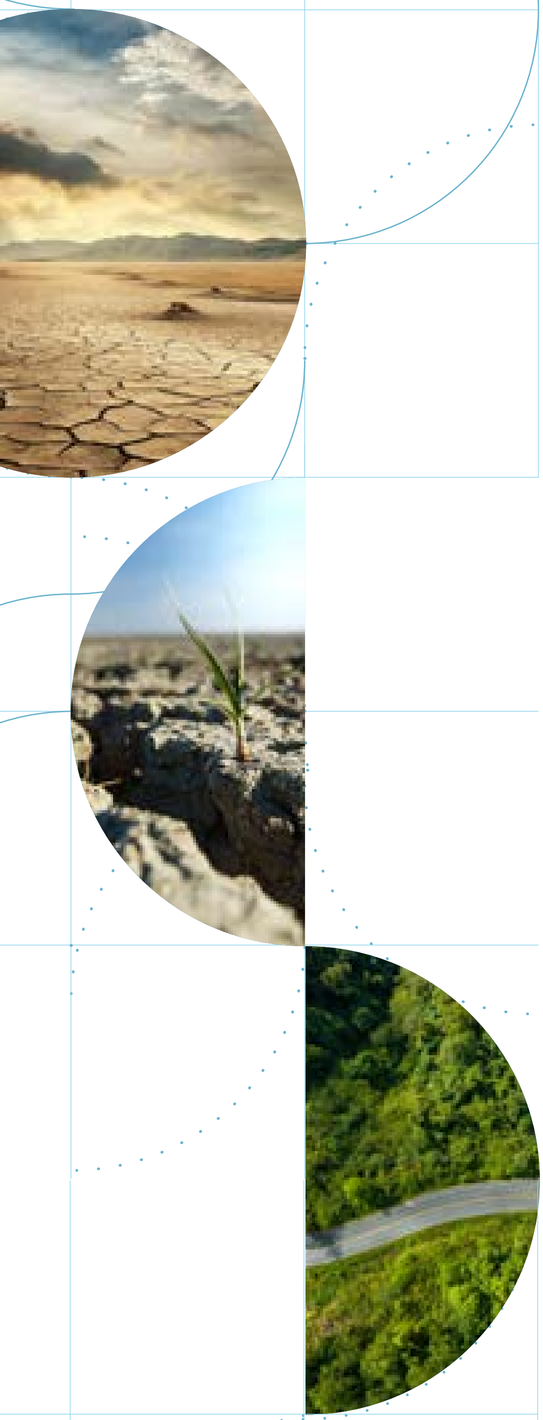
The path to FOAK is shaped by decisions made years earlier – in technology architecture, regulatory strategy, partnership structures, and pilot design – whose consequences only become fully apparent when a company arrives at the financing table. These are not mistakes of individual companies so much as reflections of an ecosystem that lacks the structures and instruments the FOAK stage specifically requires. It is a structural mismatch between the agility expected of early-stage innovation and the rigidity that industrial-scale deployment demands, and closing it requires interventions across the entire ecosystem, not adjustments by any single actor.

This realization significantly expanded the scope of our research. Rather than mapping financing challenges alone, The Road to FOAK constructs a comprehensive diagnosis of the full challenge landscape that climate-tech companies encounter on their path to commercial scale: financial, operational, regulatory, organizational, and market-related, and explores the strategies, tools, and ecosystem conditions that determine whether a company can navigate it successfully.

This comprehensive, granular mapping of the barriers climate tech FOAKs face serves as a strategic roadmap. We believe that a profound understanding of these challenges is a prerequisite for developing an effective, company-specific scale-up strategy. Although the climate tech landscape spans a diverse spectrum, from B2C alternative proteins to B2G grid optimization, these sectors face similar structural obstacles. This report deliberately adopts a cross-sectoral lens to identify systemic patterns that transcend individual industries. This breadth is a strength when diagnosing structural barriers, but it carries an inherent limitation – the weight and relevance of specific risk dimensions vary meaningfully across sub-sectors. The capital flow challenges facing a green hydrogen developer, for example, differ in magnitude and character from those encountered in advanced recycling or sustainable aviation fuels. Therefore, the decision to analyze the broad spectrum of climate technologies rests on a premise but also has limitations. We encourage readers to use the challenge map as a diagnostic starting point, applying their own sector-specific judgment to assess which dimensions are most consequential for their particular technology, market, and regulatory context.

Following the challenge mapping, we introduce the Climate FOAK Playbook, synthesized from the diverse recommendations gathered throughout our research. Rather than a fixed "recipe" for success, this playbook identifies the critical dilemmas, and strategic options startups must navigate - ideally long before beginning their scale-up.

One strategic finding that cuts across virtually every dimension of this report is the defining role of collaboration. The path to a FOAK facility



demands a breadth of expertise that no single organization possesses: deep technical knowledge, regulatory literacy, financial structuring capability, supply chain management, market development, and the operational discipline of running an industrial facility at scale. What emerged consistently from our interviews and analysis is that the companies that navigate this complexity most successfully do not attempt to build all of these capabilities in-house. Instead, they construct ecosystems of partnerships: with investors who bring not just capital but sector-specific expertise, public institutions that shape the regulatory environment, and corporate offtakers who transform uncertain demand into bankable revenue. These collaborations are not peripheral to the FOAK journey; they are structural to it. They appear in every risk dimension and strategic recommendation examined in this report. Understanding the FOAK stage, therefore, means understanding not just what a company must do, but who it must do it with.

Methodology and Approach

The research underlying this report rests on three complementary pillars. First, a systematic literature review encompassing academic research, policy reports, and industry publications from leading institutions such as the U.S. Department of Energy, the European Commission, McKinsey & Company, Sightline Climate, and the True North Institute. This review synthesizes the current state of knowledge and identifies the specific gaps this report aims to address. Second, in-depth interviews with a diverse group of 25 key players in the international climate tech ecosystem. This group includes founders who have successfully deployed FOAK facilities, venture capital investors, infrastructure financiers, corporate partners, and regulatory experts. We held conversations with experts from Germany, the United Kingdom, the United States, and Israel, with experience in projects in their local countries, Latin America, and China. The conversations held with these actors are not merely illustrative; they are the primary mechanism through which we tested our hypotheses, refined our challenge map, and grounded theoretical frameworks in lived experience. Third, a structured questionnaire was administered in collaboration with KPMG to tech companies and investors to quantify the patterns and priorities that emerged during the interview process. In total, the questionnaire reached 18 climate-tech companies and 13 investors across multiple geographies, spanning the United States, Germany, the United Kingdom, and Israel. Respondents were asked about their financing experiences, risk perceptions, partnership structures, and the conditions that would most increase their confidence in FOAK investments. The questionnaire was designed to quantify patterns that emerged from the interview process, and its findings are referenced throughout the report to ground qualitative insights in structured data. The results should be interpreted with the limitations of a relatively small and self-selected sample in mind.

This human-centered, mixed-method approach is a deliberate methodological choice. The FOAK stage is not well captured by aggregate financial data alone. The decisions that determine whether a project succeeds or fails are made by people operating under uncertainty, navigating relationships, and exercising judgment in difficult-to-model conditions. By drawing on first-hand accounts from founders, investors, and regulators, this report translates qualitative experience into structured, actionable insight.

The challenge mapping component of the report was structured around the Adoption Readiness Level (ARL) framework, which the US Department of Energy (DOE) designed to complement the widely used Technology Readiness Level (TRL) scale, also developed by the DOE. The ARL maps the non-technical barriers that determine whether a technology can achieve commercial adoption. The report adapts the ARL's architecture to the specific context of climate FOAK projects and maps the various challenges according to its structure.

What Sets This Report Apart

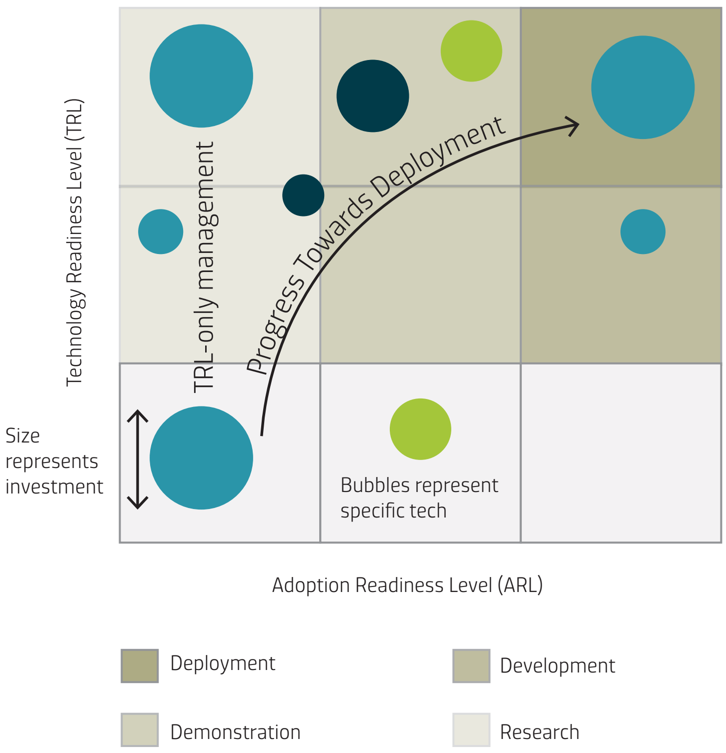
The Road to FOAK builds directly upon the foundations laid by previous research – including the CREO FOAK Framework (CREO, 2024), the FOAK Guide (Sightline, 2024), and broader commercialization studies, including Barriers to the Timely Deployment of Climate Infrastructure (Khatcherian, 2022), Learning From 18 Foak Climate Technology Investment Case Studies (True North Institute, 2025) and 2025 Annual Knowledge Sharing Report (Innovation Fund, 2025). It extends the conversation in four directions. First, it focuses specifically on FOAK projects, isolating the first-project phase as a transitional step in the journey to scale, with its own challenge ecosystem. Second, it goes beyond financial and technological challenges to explore the operational, regulatory, and organizational hurdles that shape the path to deployment and the complex interplay between them. Third, the report links micro and macro perspectives. It connects the tangible realities of project execution: financing delays, contracting structures, team composition, etc., with macro-level forces such as policy design, investor behavior, and capital-market expectations. Fourth, it aims to provide actionable guidance for multiple stakeholders. It does not address a single specific stakeholder category but rather maps the interconnected roles of entrepreneurs, corporates, financiers, and governments, illustrating how alignment between them determines whether a FOAK succeeds.

This inclusive, broad yet granular framing turns the report from a research document into a multidimensional coordination tool, providing a shared language and helping diverse actors recognize their shared responsibility in transforming innovation into infrastructure. By forecasting the near-term landscape, this mapping can prepare stakeholders across sectors and positions to navigate climate FOAK financing and deployment with precision well before they reach the crossing.

Structure

This report is organized to serve as both a diagnostic tool and a practical guide. The first chapter presents the comprehensive challenge mapping structured around the ARL framework, categorizing the barriers climate-tech companies face across four risk areas: Value Proposition, Market Acceptance, Resource Maturity, and License to Operate. Within each risk area, individual risk dimensions capture the specific, granular challenges that companies encounter on the path to deployment.

Then the Climate FOAK Playbook translates that diagnosis into action, providing detailed strategic guidance for both startups preparing to scale and the ecosystem actors who have the ability and the responsibility to support them. Woven throughout both sections are three spotlight case studies that bring the report's themes to life through concrete experience: LanzaTech, whose capital-light licensing model and proactive regulatory engagement offer a proven template for FOAK commercialization; UBQ Materials, whose journey illustrates a distinct set of challenges and strategies in the waste-to-value space; and an examination of China's emerging climate FOAK ecosystem, which offers a striking comparative perspective on how policy architecture, financing structures, and industrial capacity interact to shape deployment outcomes.



Source: US Department of Energy

ARL US Department of Energy

Together, these elements function as an integrated toolkit – a resource that stakeholders can return to at different stages of their journey to navigate the road to FOAK with greater foresight and preparedness.

This report would not have been possible without the generosity of the international climate technology ecosystem. In the course of our research, we spoke with founders, investors, policymakers, and project developers across multiple continents, and were met, without exception, with openness and a willingness to share hard-won knowledge. We are deeply grateful to everyone who gave their time to this work, and we hope that this report embodies the same collaborative spirit in which it was made.

Challenge Mapping

Mapping the barriers to FOAK deployment requires filtering noise from signal.

Launching a new venture is never simple, but some sectors impose higher barriers than others. Every entrepreneurial process involves creating something new. Yet the degree of innovation varies: some businesses are new only in branding or business model, while others challenge themselves to develop a novel technology, develop a product and demand around it, and sometimes even design new facilities and processes. In climate deep tech, these challenges are compounded: the path to market requires not just a prototype, but the construction of FOAK commercial facilities, where scientific risk meets execution reality.

Mapping the barriers to FOAK deployment requires a mechanism to filter noise from the signal. Our methodology applies a root-cause analysis to uncover origins and assess consequences. This process often reveals that seemingly isolated engineering or financial hurdles stem from the same core systemic gap. Furthermore, it helps classify the nature of the resistance: distinguishing between 'blockers' that must be removed for the ecosystem to thrive, and 'inherent challenges' that are simply the nature of industrial innovation.

While any attempt to fully separate challenges from one another is imperfect, digging into the details reveals sharper distinctions. We therefore broke our challenge map down to the most granular dimensions possible. Even so, it is evident that many remain interlinked. For example, supply chain challenges are closely tied to regulatory instability, and delivered costs often depend on capital flow. Where relevant, we highlight these relationships between dimensions, accurately depicting the context in which climate FOAK projects operate.

This chapter details the specific FOAK challenges identified through our extensive interviews and material analysis. To provide a structured diagnosis, we utilize the DOE’s Adoption Readiness Level (ARL) framework, categorizing barriers into four key risk areas. Values Proposition, which examines the technology’s ability to deliver cost-competitive functionality; Market Acceptance, which analyzes the economic landscape and demand maturity; Resource Maturity, addressing the critical inputs required for production – capital, supply chain, and talent; and License to Operate, which covers the regulatory and social permissions needed for deployment. Each area is further deconstructed into granular risk dimensions, breaking down high-level challenges into the specific, tangible obstacles that projects face during scale-up.

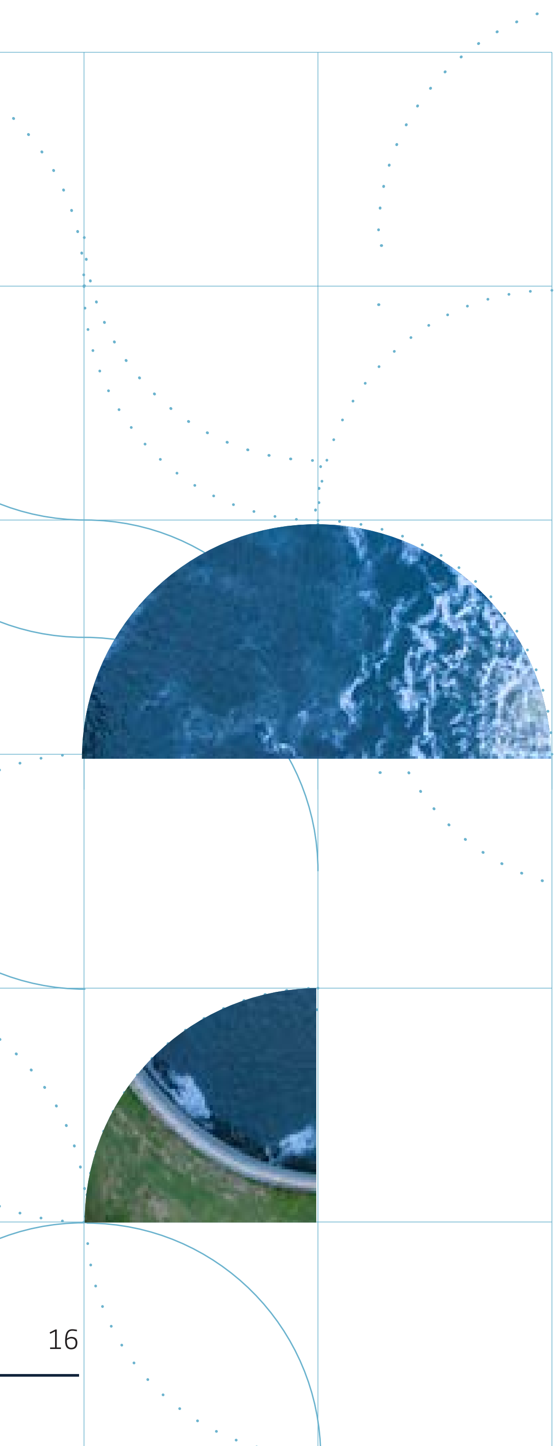
Without a compelling value proposition for relevant customers, even the most scientifically advanced solutions will struggle to scale and thus fail to achieve meaningful climate impact.

A. Value Proposition

The first risk area in the ARL framework concerns the technology's value proposition – its ability to deliver functionality and benefits that the market recognizes and is willing to pay for. While many climate-related innovations demonstrate promising results in laboratory settings, this technical success does not automatically translate into commercial viability. Without a compelling value proposition for relevant customers, even the most scientifically advanced solutions will struggle to scale and thus fail to achieve meaningful climate impact.

Placing the value proposition at the model's initial risk area underscores its foundational role: climate-tech ventures may create environmental and societal benefits, but their viability depends on generating economic value for customers and stakeholders who ultimately sustain their deployment. In other words, climate impact cannot be realized unless the technology also provides clear, competitive, and enduring market value.

This risk area is assessed through three interrelated dimensions: delivered cost, which captures whether the technology can achieve cost competitiveness at scale; functional performance, which evaluates the ability to meet or exceed the standards of incumbent solutions; and ease of use, which reflects the operational and integration challenges for potential adopters. Together, these dimensions provide a structured lens for understanding whether a technology's promise in the lab can translate into market adoption.



A.1. Delivered cost

Delivered cost refers to the risks associated with the direct cost of the technology to the client. It is based on the ratio between the cost of the solution to customers and the impact it provides them. It does not consider the implementation costs or implementation process but isolates the question of whether the solution can reach and possibly beat cost parity with incumbents, while accounting for risks such as volatile input prices or customer switching costs. In essence, it measures whether the technology can deliver its value at a price point the market is willing to pay - a critical condition for adoption and scale-up.

A unique aspect of the delivered cost challenge in climate tech is that the environmental value created does not automatically translate into economic value. While the 'green premium' initially suggested that customers would pay more for sustainable alternatives, it often proved to be a temporary condition – a fragile subsidy that collapses the moment a cost-parity alternative appears.

Although many companies initially relied on the green premium, market history demonstrates a preference for economic rationality, consistently favoring solutions that offer superior cost and performance over those that rely mostly, or even solely, on environmental virtue (WEF & BCG, 2025). Ultimately, sustainability scales only when it becomes cheaper and better, not just greener, despite the significant value it creates.

As Jack Haynes, Partner at The True North Institute, said:

> *"If I were a villain and I didn't care about the climate, would I buy this company purely on that basis? This serves my own interest. The business needs to be profitable and on a stand-alone basis. Otherwise, it's never going to be a business."*

And Yair Reem, Partner at Extantia, further stressed:

> *"What we're currently talking about is bringing to the market technologies that are better, faster, cheaper. And they happen to be green. So, there is a climate angle. But we're not doing it because it's climate. We're doing it because it's great. Great business, great competitive advantage."*

Meaning, not only does the solution need to be relevant regardless of its green credentials, but it also needs to be priced competitively compared to its traditional alternatives. Today, the reality is that, compared with traditional competitors, most climate FOAK projects incur significantly higher R&D, demonstration, and scale-up costs. These include large upfront capital requirements, lengthy development timelines, and complex construction processes. As a result, their delivered cost often starts at a disadvantage, making it harder to compete with incumbents that benefit from established infrastructure, mature supply chains, and lower financing risks. This cost imbalance amplifies the challenge of achieving long-term cost competitiveness and market adoption (OCED, 2024; Mkhize, 2023). In addition, specifically in heavy industries, which are more energy-intensive, many of the FOAKs aim to use renewable energy sources, making the production costs even higher, especially in hard-to-abate sectors (BloombergNEF, 2025; Innovation Fund, 2025).

A.2. Functional Performance

Challenges relate to a technology's ability to deliver its promised functionality under real-world conditions at commercial scale. Under the ARL framework, this dimension evaluates whether the solution meets or exceeds the performance standards of incumbent technologies or, alternatively, creates a new market by offering superior features. For FOAK projects, this means not only proving that the technology works but also demonstrating that it can run reliably, integrate into existing systems, and deliver consistent outcomes over time.

One of the central challenges is the uncertainty caused by the absence of historical performance data, a theme that recurs across several risk areas. Unlike mature technologies, FOAK projects lack long-term operational track records that investors and adopters can rely on. Demonstration projects can help, but variability around expected outcomes remains significantly higher than for established solutions. As a result, potential customers not only face uncertainty about the technology's productivity but also encounter difficulties planning the supporting systems and related infrastructure required for its deployment (True North Institute, 2025).

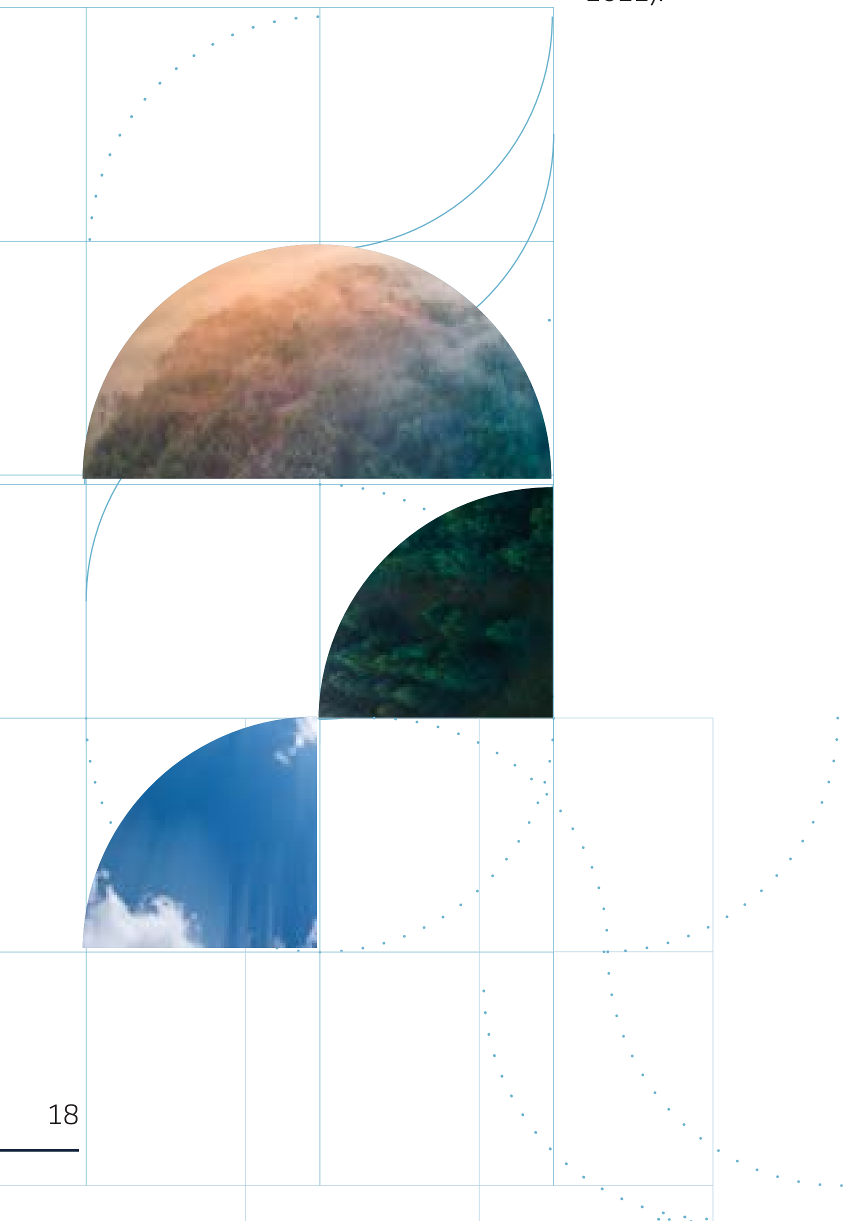
Variability in input materials poses additional risks, especially in recycling and nature-based solutions. A lack of standardization in input data can lead to inconsistent outputs, undermining customer trust. For example, one startup developing environmentally friendly materials found that changes in input feedstock required entirely new design and manufacturing adjustments, delaying progress and complicating adoption (Sefton et al., 2020).

In practice, functional performance must be demonstrated at the highest possible fidelity before first commercial deployment. As highlighted in the Sightline FOAK Guide, companies must prove that their systems can operate for extended periods, achieve reliable throughput, and sustain projected cost and efficiency metrics. These performance demonstrations are crucial key performance indicators (KPIs) for attracting financing, securing partnerships, and ultimately derisking scale-up.

A.3. Ease vs. complexity of implementation and use

Another barrier lies in implementation and integration at scale. Technologies that function in controlled pilot environments may encounter setbacks when scaled up, particularly when they must adapt to existing infrastructure or operate alongside complementary technologies. During pilots, integration is typically managed by experts, but this does not reflect the realities of commercial deployment. As a result, the technology may not be adequately adapted for large-scale operations teams, who often lack the training, experience, or resources to run it effectively, leading to errors, delays, higher maintenance costs, and reduced reliability. Integration challenges also extend to system-level compatibility, where new solutions must be interoperable with current infrastructure or business models to gain acceptance and be considered economically viable (Khatcherian, 2022).

> To achieve adoption and scale, FOAK technologies must meet a threefold test: deliver value at a competitive price, demonstrate reliable performance over time, and successfully transition from controlled pilots to complex, real-world deployment



SPOTLIGHT
LanzaTech: Scaling Through Partnerships

Instead of owning and operating all of its plants, LanzaTech built diverse partnerships allowing for significant growth through a capital-light licensing model.

How a capital-light licensing model and proactive policy engagement accelerated FOAK commercialization

LanzaTech is a compelling example of a carbon-management company that has successfully crossed the FOAK barrier and scaled from lab concept to global commercial deployment. Nearly two decades after its founding, it captures and reuses carbon emissions at 6 plants around the world – 4 in China, 1 in India, and 1 in Belgium - and is currently developing more than 40 plants internationally. By the end of 2025, LanzaTech had avoided more than 750,000 tons of CO_2 emissions with its carbon recycling technology and is currently expanding into new markets – from sustainable aviation fuels to alternative proteins. By 2025, LanzaTech secured more than $800 million in partner-committed capital across its portfolio (LanzaTech, 2022, 2024, 2025) and built strong partnerships with industrial emitters, including aviation leaders and global consumer brands. This unique roadmap, built upon multiple partnerships and diverse business strategies across diverse industries, establishes LanzaTech as a prominent case study, offering a proven model for successfully scaling climate technology.

Founded in 2005 in New Zealand and now headquartered in the United States, LanzaTech converts industrial waste gases into ethanol and other chemicals using a proprietary gas-fermentation process powered by engineered microbes. From the outset, the company recognized that it could not create a new production pathway on its own. Instead of owning and operating all of its plants, LanzaTech built diverse partnerships allowing for significant growth through a capital-light licensing model, in which industrial partners finance, build, and operate the facilities, while LanzaTech supplies the microbes, process technology, engineering services, and long-term support, or owns the plants together with local and strategic partners. This flexible approach enabled rapid scale-up.

LanzaTech's first commercial-scale gas-fermentation facility, launched in 2018 at the Shougang steel mill in Beijing, reflected more than a decade of technical scale-up and a distinctive customer-financed deployment strategy. The facility was developed through a joint venture (JV). The Beijing Shougang LanzaTech New Energy Technology Co., Ltd., which had already operated a demonstration plant at the site. The JV and Shougang jointly financed the commercial FOAK, enabling LanzaTech to deploy without bearing project finance risk. By 2022, LanzaTech had built two additional commercial plants in China.

The company's strategic decision to collaborate through licensing models enabled its rapid scale-up. LanzaTech partnered with industrial players such as ArcelorMittal, IndianOil Corporation, and Sekisui, which provided direct access to feedstock at the plants and operational infrastructure, substantially reducing siting and permitting risk during the development stage and throughout supply chain operations.

Credit:LanzaTech

“The company never waited for policy to catch up; instead, it worked proactively with governments, NGOs, unions, and industry groups to shape the regulatory environment.”

Unlike most climate-tech startups, which typically launch FOAKs in the U.S. or Europe (IEA, 2023), LanzaTech began its commercial journey in China. This strategy, combined with the Shougang partnership, allowed the company to benefit from faster permitting, resulting in a four-year process for permitting and building the FOAK, compared to the 4–5-year U.S. permitting average (McKinsey & Company, 2025). By capitalizing on China’s streamlined regulatory environment, lower construction costs, and abundant industrial off-gases for technical validation, LanzaTech rapidly accelerated its transition from pilot testing to full commercial operations, significantly derisking future facilities.

However, the China-first approach also has trade-offs: the JV structure limited revenue capture, operational visibility, and transparency. Because the plant was built by the JV, the project’s financials were less transparent to external stakeholders. Combined with the fact that performance data from FOAKs built under different permitting or quality standards is often discounted by Western financiers and regulators, this created additional hurdles when translating China-based success stories into U.S. and European investment. Deploying FOAK technologies internationally can introduce additional challenges. The OECD (2021) and the World Economic Forum (2022) note that cross-border projects increase exposure to IP leakage risks. Still, the experience offered foundational learning and industrial credibility that supported subsequent deployments in Europe, India, and the United States.

LanzaTech’s collaborative model is built on actively engaging all relevant stakeholders, including partners, clients, suppliers, and regulatory bodies, to ensure alignment and continuous learning across projects and sites. This approach is especially evident in the company’s policy and regulatory strategy, critical for FOAK derisking. As Freya Burton, LanzaTech’s Chief Sustainability Officer & Head of Europe, emphasized, the company never waited for policy to “catch up.” Instead, it worked proactively with governments, NGOs, unions, and industry groups to shape regulatory conditions. Burton even relocated to Brussels to engage directly with policymakers, explaining:

“It wasn’t lobbying in the sense of ‘you need to do this.’ It was literally just explaining, ‘here’s what the technology is, here’s what the opportunity is, and here’s what the downside is if you don’t include this.’”

She noted that policymakers often lack technical capacity and appreciate direct, accessible information, and she observed how LanzaTech's input helped make grant language "more open" over time. Her core message to climate-tech founders: many "neglect policy completely... until they suddenly need to sell," while shaping markets and rules is a defining FOAK capability. This is an illustration of the Regulatory Environment (D.1) challenge: when a technology falls outside existing categories, regulatory engagement is not optional – it is a core commercialization capability.

Lastly, complementing this rapid deployment strategy, LanzaTech adopted a commercial model that diverges from the traditional heavy industry focus on vertical depth. LanzaTech used a strategy of horizontal diversification across a broad spectrum of products and client base. By deploying its carbon capture utilization platform to produce a range of outputs – including Sustainable Aviation Fuel (SAF), alternative proteins, textile materials, and industrial chemicals – the company effectively mitigated commercial risk through a multi-market approach. This strategy has allowed LanzaTech to validate its technology across disparate sectors and geographies, derisking market adoption by ensuring that regulatory or economic challenges in one industry can be offset by growth in others. This approach directly addresses the Market Size (B.2) risk: by distributing across sectors and geographies, LanzaTech avoided the trap of a small, regulatory-dependent early market that could have constrained its growth trajectory.

> By distributing across sectors and geographies, LanzaTech avoided the trap of a small, regulatory-dependent early market that could have constrained its growth trajectory.

LanzaTech's branding strategy is also adapted over time to serve different partners and markets. Industrial partners such as ArcelorMittal, IndianOil, and Sekisui are engaged through a decarbonization and compliance narrative, while consumer-facing companies such as Zara, H&M Move, On Running, Danone, Unilever, and Coty have been served through the CarbonSmart™ brand, LanzaTech's brand for materials and products made from recycled industrial carbon, highlighting circularity and recycled content. In the aviation sector, LanzaTech launched and spun off LanzaJet in 2020, a dedicated identity for a sustainable aviation fuel company, with large investors such as IAG, Shell, Mitsui, and others. These differentiated brands and value propositions enable the company to effectively engage policymakers, industrial emitters, chemical converters, retailers, and end consumers, all essential to scaling a multi-stakeholder growth roadmap.

credit: LanzaTech

Takeaways for Climate-Tech FOAK Innovators

- Build through partnerships, not ownership. Align with incumbents who can supply feedstock, capital, and credibility to focus the company's energy and resources on its comparative advantage.
- Adopt a capital-light model. Focusing on the company's comparative advantage and leveraging partners' capabilities can significantly reduce risk.
- Use each FOAK as a learning asset. Treat early plants as platforms for technical and financial iteration. They don't have to represent your long-run project prototype, but derisk what's possible.
- Engage regulators early. Shape frameworks rather than waiting for them to form; policy literacy is as critical as engineering skill.
- Tailor branding and value propositions to each stakeholder segment across the supply chain.

B. Market Acceptance

While the Value Proposition highlights the technological and operational aspects of integrating and selling the technology, market acceptance focuses on the economic aspects of the business model. It discusses the market's characteristics, examining the suitability of the company and product to the market's needs, and the likelihood that it will succeed in scaling in the current environment. Crucially, companies are not merely subject to market conditions; they possess the 'catalytic power' to reshape them. While the challenges outlined in this chapter are often viewed as external constraints, aware organizations can fundamentally alter these factors through strategic intervention. This is evident in two distinct cases. In the B2C sector, Tesla ignited demand for electric vehicles (EVs) through innovative marketing and product positioning. Global EV sales, which stood at less than 250,000 units annually prior to Tesla's mass-market entry, surged to 2 million by 2018 and exceeded 17 million in 2024 (IEA, 2025). Similarly, in the B2B space, Ørsted transitioned to an 85% offshore wind portfolio before the market recognized the sector's potential. By aggressively driving industrial productivity, they effectively 'created' the market, forcing the technology down the cost curve and establishing a new asset class (Bower & Corsi, 2018).

> Customers may persist with incumbent, even underperforming, approaches rather than absorb the risks and costs of switching to a novel solution.

B.1. Demand Maturity / Market Openness

FOAK climate projects often emerge in nascent markets, where customer demand remains uncertain, and the willingness to adopt untested solutions is limited. Markets for some FOAK outputs, such as renewable hydrogen

Credit: CleanTech Lithium

FOAK technologies are confined to a narrow market of early adopters willing to bear uncertainty.

or sustainable fuels, are in their infancy, creating uncertainty both about the competitiveness of the product and the durability of demand (CREO, 2024; OCED, 2024). In these contexts, startups encounter the challenge of strategic fixedness: customers may persist with incumbent, even underperforming, approaches rather than absorb the risks and costs of switching to a novel solution.

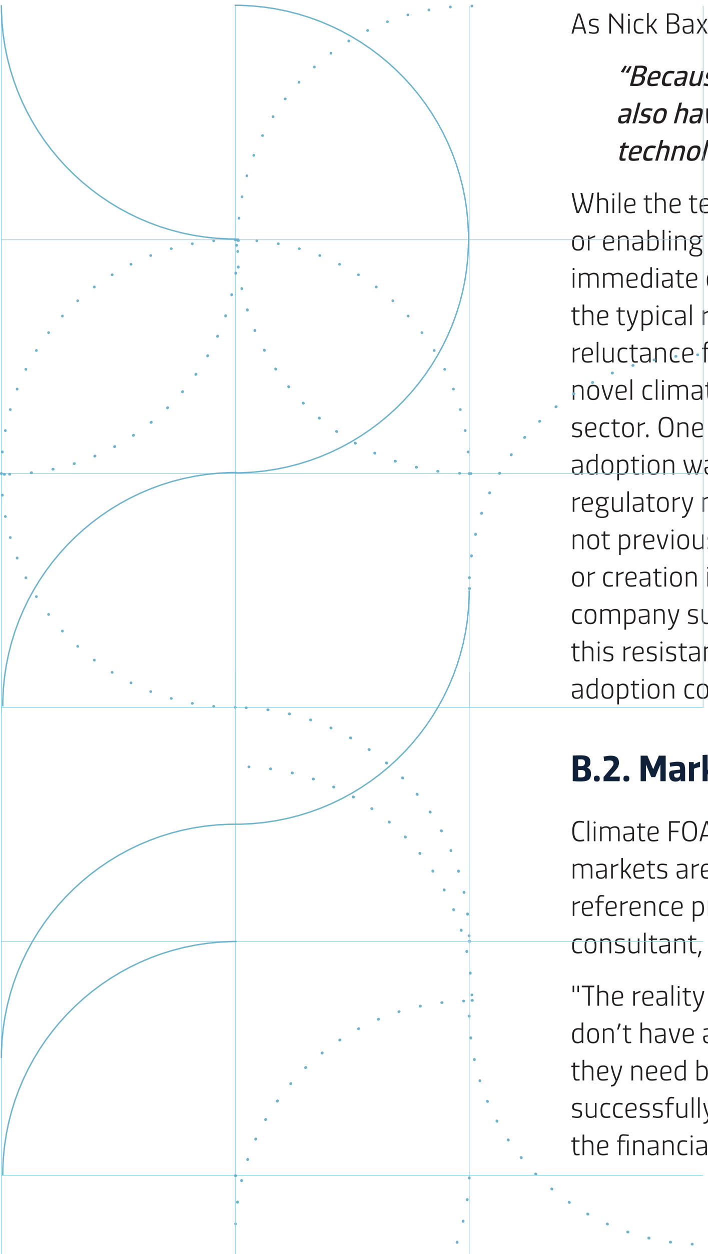
Furthermore, support systems designed to foster entrepreneurship are not yet fully tailored to address this gap. While most climate-tech support programs in global hubs facilitate access to capital, fewer than a quarter help startups connect with customers or talent, and very few are tailored to the specific needs of hardware-based companies (Endeavor, 2022). For FOAK developers, this exacerbates the difficulty of securing critical offtake agreements – binding commitments from customers to purchase future output – which are essential to achieving financial close. For example, this issue is particularly acute in hydrogen projects, where uncertainty about cost competitiveness makes long-term demand commitments difficult to secure (European Innovation Fund, 2025). Without such demand-side assurances, projects face delays, cost overruns, or cancellation.

Several startups we interviewed mentioned that a significant challenge is that they are creating a product that "hasn't yet seen any defined market," requiring them not only to prove the technology but also the product's commercial necessity.

As Nick Baxter, Head of Communications & ESG at CleanTech Lithium, said:

> *“Because not only do you have to prove the technology, but you also have to demonstrate that there is commercial incentive for this technology.”*

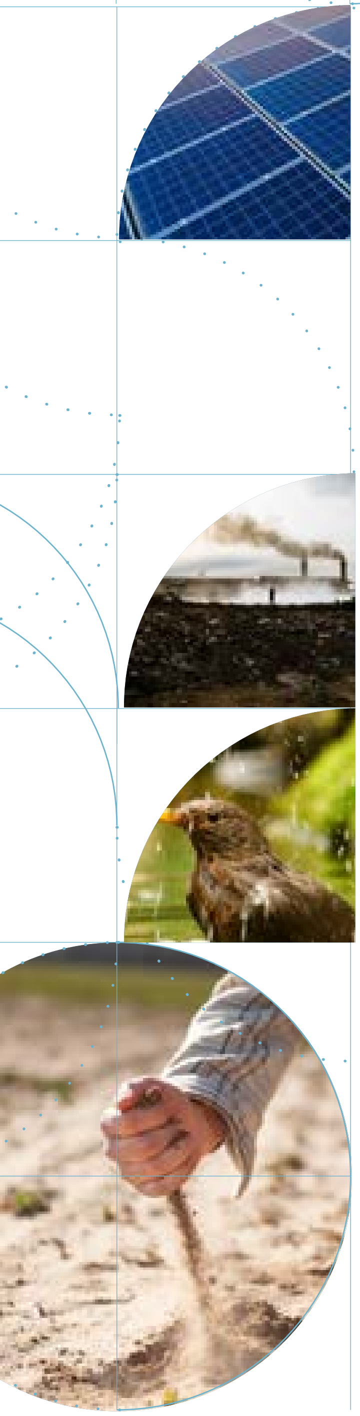
While the technology’s primary incentive lies in reducing emissions or enabling more sustainable alternatives, customers often prioritize immediate economic benefits. As a result, these technologies not only face the typical resistance associated with novelty but also encounter a broader reluctance from markets that struggle to recognize the tangible value of novel climate solutions, potentially creating skepticism toward an entire sector. One specific example is LanzaTech, which found that its technology adoption was hampered in Europe because the market, despite being under regulatory mandates, was not configured to support technologies that had not previously been implemented, demonstrating that market adoption or creation is a major challenge. Interviewees emphasized that once a company succeeds in financing and executing its FOAK project, much of this resistance and skepticism tends to diminish, making subsequent adoption considerably easier.



B.2. Market Size

Climate FOAK technologies face pronounced market-size risks, as these markets are nascent and evolve slowly; therefore, credible benchmarks and reference project data remain scarce. As Deanna Zhang, FOAK financing consultant, put it:

"The reality is that founders are often building in the dark. They simply don’t have access to the precedent data or historical performance metrics they need because there aren't enough examples of projects that have successfully scaled and shared that information publicly. As a result, the financial models we see are often not up to institutional-investor



standards. Founders are forced to make assumptions without the necessary benchmarks to stress-test the economic boundaries of their project early enough in the process."

In parallel, FOAK solutions must compete against incumbent fossil-based technologies that are cheaper, widely available, and embedded in established industrial ecosystems. As a result, adoption often depends on regulatory incentives or sustainability mandates, confining its initial market primarily to regions or organizations with strong environmental commitments (Mkhize, 2023).

In addition, the long development and implementation timelines typical of FOAK projects further narrow the customer base to actors with long-term strategic horizons and the financial capacity to absorb delayed returns. In low-margin industries such as food processing, where costs are sensitive, and risk aversion is high, customers are especially hesitant to adopt unproven technologies. As several interviewees noted, potential customers frequently prefer to wait until a technology demonstrates reliable, full-scale operation before engaging.

Altogether, the combination of uncertain performance data, higher costs relative to incumbents, and extended project cycles results in a small, cautious, and highly selective market. This limited early demand not only slows commercialization but also undermines investor confidence, reinforcing the structural challenge of achieving the scale needed to make FOAK climate technologies cost-competitive.

B.3. Downstream Value Chain

Risks associated with the downstream value chain serve as the connector between internal and external factors affecting FOAK's success. This element concerns the design of the value chain that should ensure the product is not only designed efficiently and productively, but also manufactured, shipped, and integrated smoothly at its destination.

First, the incentives of the critical decision-makers involved should be considered. Additionally, an extensive analysis should be undertaken of potential downstream interruptions involving suppliers, manufacturers, shipping companies, regulators, and other stakeholders. Potential split incentives, either between the company and an external stakeholder or between the various stakeholders themselves, could cause unexpected disruption and the rethinking of the downstream design.

Dependency on external permitting or infrastructure (such as pipeline laying to transport CO2 or hydrogen, as well as grid connection infrastructure) can lead to synchronization risk. Issues affecting these external activities can have a significant impact on the project timeline or viability, as project completion depends on the timely completion of the downstream supply system managed by a third party. While the infrastructure risk dimension (detailed in Resource Maturity, Section C.3) addresses whether large-scale systems are in place to support deployment, the downstream value chain risk captures the operational impact of depending on the permitting and timely delivery of the external system needed to move the product to the customer (Innovation Fund, 2025).

In addition, volatility of relevant commodity markets such as plastics, aviation fuel, and hydrogen, which are even more volatile when in their “green version”, challenges long-term planning of pricing and business models, as well as operational design of the supply chain. As Jack (Tato) Bigio, Co-Founder & Chief Expansion at UBQ, mentioned:

“Plastics are not so long-term as opposed to oil or even wheat or sugar, that you have the Chicago Board of Trade and you have three-year contracts, plastics are not even six months. You cannot commit to a price, so nobody wants to close. Everybody wants to stay afloat. So, you can’t make a project finance structure."

Lastly, the slow development of necessary transport infrastructure, for example, hydrogen or other key customer feedstocks, often results in fragmented supply chains that increase the complexity of securing reliable, long-term commitments on timing and pricing (Innovation Fund, 2025).

SPOTLIGHT
UBQ: Supply Chain Integration and Circular Economy Value Chains

Banks wanted contracts first; the contracts required a functioning plant first - creating a classic chicken-and-egg dynamic.

UBQ Materials is a climate and materials company (founded 2012) that converts mixed municipal solid waste (MSW), including all the organic content, into UBQ™, a thermoplastic composite that can replace conventional oil-based plastics in manufactured goods. UBQ’s first commercial-scale FOAK facility in Bergen op Zoom (BOZ), the Netherlands, marks the company’s transition from a commercial, R&D-oriented pilot line in Israel to a fully automated, large-scale industrial asset designed for 24/7 operation. The FOAK journey illustrates a common climate-hardware pattern: 1) scale-up is as much about industrial execution as about chemistry; 2) bankability depends on contracting norms (the plastics industry rarely offers classic offtake contracts), and 3) macro shocks can materially reshape CAPEX and timelines.

UBQ’s FOAK facility is a modular, six-reactor site designed for a staged ramp-up, converting ~104,600 t/y of waste into ~80,000 t/y of UBQ material. The project’s ~$170M CAPEX reflected COVID-era supply chain inflation and was funded primarily through equity, as the lack of traditional long-term sales contracts precluded commercial bank debt. Following a 2021 financial closing and 2023 construction phase, the facility achieved initial production in late 2023, with full operational scaling throughout 2024.

UBQ’s story underscores the structural gap between its country of origin's strong national R&D engine and its relatively weak industrial setup for

UBQ Facility in Bergen op Zoom, the Netherlands. Source: UBQ

Moving from “it works” to “it works safely, consistently, and profitably at scale” requires a different level of engineering discipline, supplier management, and operations readiness.

capital-intensive manufacturing: limited technical-vocational pipelines, limited local market pull, and the absence of a dedicated enabling environment for FOAK industrial assets. UBQ’s leadership also emphasized the financing gap that typically accompanies FOAK industrialization: beyond equity, there was limited access to other forms of capital on terms that matched FOAK risk, given the lack of long-term revenue certainty lenders usually require. This is illustrative of where blended finance can be catalytic - by crowding in private capital through risk-sharing tools (e.g., guarantees, first-loss layers, or concessional tranches), helping bridge the “bankability” gap until the first plant produces the operating data and commercial traction needed for mainstream project finance. Finally, policy stability and a credible legal environment are critical for attracting capital, while a stronger industrial base - skills, machinery suppliers, supporting regulation, and supportive industrial zones - is essential for countries targeting more hardware companies to build and operate FOAK plants locally.

UBQ’s process is designed to handle mixed waste streams, including all organics present in household waste, which are typically sent to landfills or incinerators. Operationally, the company highlights the variability of household waste - particularly high moisture and feedstock “contamination” (inert materials like glass, stones, and metals that need to be removed) - and the need for robust pre-processing, separations, and control systems to ensure consistent feedstock to assure UBQ thermoplastic pellet quality.

UBQ’s pilot site was a hybrid between an industrial pilot and an R&D plant: intentionally manual, flexible, and optimized for experimentation and rapid iteration. In contrast, the Netherlands FOAK is “a completely different animal” - a fully automated line expected to operate continuously (24/7, 365 days a year), with SCADA[1] safety systems, and industrial-grade reliability requirements. This transition required not only technology transfer but also an “industrialization” step: hardening the process to run nonstop, standardizing quality controls, and building a production organization that can sustain uptime and throughput without the constant adjustments typical in R&D mode. UBQ’s leadership emphasized that this is where many climate hardware companies underestimate risk: moving from “it works” to “it works safely, consistently, and profitably at scale” requires a different level of engineering discipline, supplier management, and operations readiness.

The BOZ build took place during a uniquely challenging period for industrial projects: COVID-era logistics disruptions and post-2022 volatility in European supply chains. UBQ faced extreme shipping constraints, sharp increases in energy prices, and shortages of construction inputs such as

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[1] Supervisory Control and Data Acquisition

cement and concrete, as well as electronic systems – factors that extended timelines and pressured CAPEX. UBQ's mitigation approach centered on proactive supplier relationships and maintaining alignment by framing BOZ as the first of multiple future plants, creating credible long-term upside for equipment providers willing to stay flexible during disruptions. These cascading disruptions exemplify the Project Development, Integration, and Management (C.2) risk: external shocks compound internal complexity, making proactive supplier management and schedule resilience as critical as engineering execution.

UBQ's FOAK financing reflects a common bankability barrier for FOAK industrial assets. Commercial lenders typically require long-term sales contracts or equivalent revenue certainty as "security" for underwriting debt. UBQ built BOZ to generate the operational proof and customer volumes needed to secure those contracts, and only then refinance. In other words, banks wanted contracts first; the contracts required a functioning plant first - creating a classic chicken-and-egg dynamic. UBQ also noted that plastics markets do not usually operate with the take-or-pay offtake contracts common in commodities like energy or agriculture. Instead, commitments often take the form of LOIs/MOUs and later qualification-based purchasing, putting more burden on the producer's credibility, quality consistency, and pricing competitiveness. This market structure reinforces the need for equity at FOAK and underscores why derisking instruments - guarantees, first-loss capital, or contract-backed demand mechanisms - can be particularly valuable for circular materials scale-up.

Equity investors referenced by UBQ leadership include TPG, M&G (UK), Battery Ventures, Reuben Brothers, Eden Capital Partners, and others. UBQ also referenced a blend of minor loans and grants at the company level; a specific example is ~€5M support from Just Transition Fund linked to R&D/monitoring workstreams. In hindsight, UBQ's experience illustrates why blended finance mechanisms can be highly beneficial for FOAK-scale climate tech startups: by using risk-sharing instruments (e.g., guarantees, subordinated/concessional debt, or first-loss layers) to improve bankability, blended finance can crowd in commercial lenders earlier, reduce the overall cost of capital, and shorten the path from "equity-only FOAK" to refinanceable project finance.

UBQ framed its market entry into the framed plastics market as a "credibility problem" as much as a technical one: entering a sector dominated by large incumbents for over a century requires a compelling value proposition and extensive independent validation. Various failed attempts to create alternative plastic materials to replace conventional plastics have also created a skeptical environment to test innovative

UBQ Facility in Bergen op Zoom, the Netherlands. Source: UBQ materials. UBQ stressed that it approached commercialization by deliberately over-investing in certification and documentation, delaying public-facing marketing until key claims - performance, safety, and climate impact - were duly substantiated by top international certifying agencies and laboratories. Then, the company showed a focus on engagement with major global brands (e.g., Mercedes-Benz, PepsiCo, McDonald's) as an indicator of the level of scrutiny they have met as a supplier. Securing these brands as potential clients for a large-scale operation sparked interest among tens of manufacturers in testing the use of UBQ across furniture, construction, logistics, the car industry, 3D printing, and more. The market realized that a newcomer could finally address manufacturing quality standards, quality, and material performance while offering an entirely different environmental value proposition to support their sustainability targets. This experience illustrates the Demand Maturity (B.1) challenge at its sharpest: in markets scarred by prior failures, credibility must be built before demand can be unlocked.

On pricing, UBQ's strategy was to compete at or below conventional plastics pricing where possible, using discounts to secure early volume and accelerate penetration. The rationale is that many alternative plastics fail to scale because they remain niche premium products; UBQ aims to be cost-competitive while delivering a stronger sustainability proposition. This pricing discipline directly reflects the Delivered Cost (A.1) challenge: in a market dominated by low-cost incumbents, cost parity is a prerequisite for adoption, not a secondary objective.

UBQ chose the Netherlands as the site for its FOAK, citing the country as a sophisticated and supportive jurisdiction for industrial innovation. BOZ progressed without major permitting obstacles, given the technology's clean and safe profile and the company's ability to provide robust engineering plans and mass balances. However, UBQ faced a material strategic regulatory challenge at the market level: classification frameworks that define "recycled plastic" in ways that can exclude novel bio-based composite materials such as UBQ™ from compliance-driven demand (e.g., recycled-content mandates in specific sectors that refer to plastic recycling rather than material recycling). Addressing these classification gaps through standards engagement, evidence, and policy dialogue can be as critical as plant performance for unlocking volume markets.

UBQ expects subsequent plants to be significantly easier to finance as the key FOAK risks become quantifiable: technology performance is proven, operating data supports warranties and insurance, and customer volumes reduce revenue uncertainty. UBQ's stated sequencing was to 1) build BOZ with equity; 2) secure contracts and stable volumes; and 3) refinance equity with cheaper debt once bankability thresholds are met. With that, potential next locations may include the U.S. (with multiple states expressing interest) and the UAE, where financing conditions and national sustainability commitments could support rapid deployment.

UBQ's leadership offered a candid view of the local ecosystem's strengths and gaps for FOAK industrialization. On the one hand, its ability to maintain a stable business environment attracted capital despite various shocks. At the same time, UBQ argued that it underperforms on the industrial foundations needed for hardware: limited technical-vocational education pathways, shortages of technicians and industrial operators, and an ecosystem bias toward managerial and professional careers rather than manufacturing roles. Combined with a small domestic market demand and limited regional market access, these factors make it difficult to justify building capital-intensive plants locally when profitability in larger, more industrialized markets can be materially higher. All these considerations, they say, should be taken into account when analyzing FOAK locations – market stability, the relevant sector environment, human capital, and target markets.

Takeaways for Climate-Tech FOAK Innovators

- Contracting norms define bankability: In markets without classic offtake contracts (e.g., plastics), FOAKs will struggle to raise debt pre-build; plan for equity-first and a refinance path.
- Certification is a commercial weapon: In conservative markets, third-party verification can be significantly more valuable than marketing; it helps turn skepticism into qualification trials and repeat purchasing.
- Macro shocks are real FOAK risks: Supply-chain disruptions can shift CAPEX and schedules; maintain supplier alignment and optionality for long-lead items.

Written by **Dr. Yaroslav Efimov,**

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C. Resource Maturity

After mapping the challenges related to the relevancy of the final product to its relevant market, the ARL framework moves to the "behind the scenes" perspective, investigating the production process both from an operational and financial point of view through the element of resource maturity, and the regulatory process under the license to operate element. The resource maturity risk area specifically identifies risks that impede the inputs required to produce the technology solution. These inputs include financial, physical, labor, and other resources needed for the scalable production of the technology.

Only slightly over 20% of VC funding in Europe has gone to hardware between 2016 and 2024.

According to a survey conducted as part of Endeavor's research on scaling climate-tech, the biggest challenges to founders are access to financial capital, availability of qualified managers, and availability of engineers or other technical talent (Endeavor, 2022). All of these fall within the resource maturity risk area, reflecting its significance.

C.1. Capital Flow:

Capital flow risks relate to the availability of capital needed to move the technology to production at scale, encompassing the total investment required, the project's risk profile, its growth timelines, and the expertise required of investors. The capital flow challenge for climate FOAK projects is not merely about the availability of money, but about the structural mismatch between the characteristics of these projects and the expectations, capabilities, and processes of existing financing channels.

FOAKs often fall into a "missing middle" or "valley of death" in financing, as they require infrastructure-scale capital but carry venture-level risks, making them unattractive to existing funding sources (Mkhize, 2023). Interviews with investors consistently revealed that FOAKs do not fit neatly into existing investment categories. On the one hand, traditional capital providers, such as banks and private equity funds, which can provide the size of investment needed for climate FOAKs, are typically risk-averse and expect stable, risk-adjusted returns. Project finance, a common pathway for large-scale infrastructure, remains largely inaccessible until a technology is derisked and backed by long-term offtake agreements. Even then, investors report that the residual risks and unknowns often remain too high for project financiers to engage in FOAK deployment.

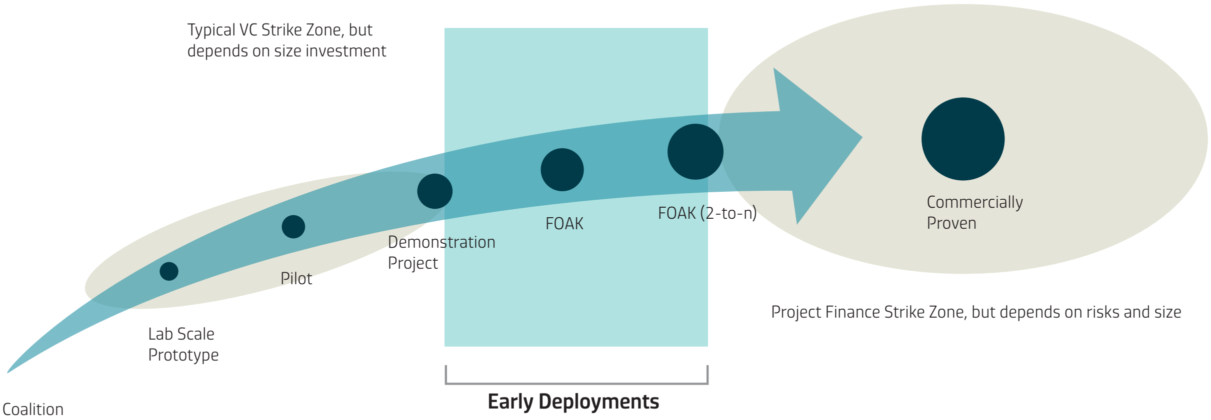
The CEO of a startup we interviewed described securing traditional bank debt for a specific project. However, as is often the case with innovative infrastructure projects, the project faced significant delays and budget overruns. This caused the bank to withdraw funding, ultimately forcing the project to shut down. In retrospect, the startup felt that involving a bank so early in the process was a mistake. The bank's exit stigmatized the project, making it impossible to secure alternative funding. This illustrates the challenges of high-risk, FOAK development with traditional lenders compared to investors who understand the inherent uncertainties of scaling new technology.

On the other hand, investors who are more comfortable with risk, such as venture capital funds, often lack experience in hardware investments, large capital requirements, or lengthy project timelines. Although hardware is gaining attention as software hits the physical limits of traditional computing and value creation shifts to specialized physical infrastructure, investment timelines have not adapted to this reality.

Economic development is becoming increasingly dependent on hardware. Deloitte forecasts that global data center electricity consumption will triple over the coming decade (Deloitte, 2025), driving a growing demand for hardware technologies to meet energy, water, and other resource needs. This, in addition to growing climate change, energy, and food security challenges, is expected to result in a dramatic rise in global hardware revenues. Yet in practice, only slightly over 20% of VC funding in Europe has gone to hardware between 2016 and 2024 (Dealroom.co, 2024)

Hardware companies typically reach close to 50 employees after five years, compared to over 120 employees for software companies (Endeavor, 2022). VC timelines are usually structured around 5-8 years, which is insufficient for the extended development, construction, and commercialization of these technologies (Khatcherian, 2022). For example, it took solar panels more than 30 years to move from initial innovation in the 1970s to widespread adoption in the mid-2010s (Khatcherian, 2022). Venture capitalists are generally more familiar with software products and business models and tend to feel more comfortable investing in them (Endeavor, 2022). In addition, even when investing in asset-heavy technologies, they typically focus on early-stage and lack the capacity to finance later-stage, larger demonstration sites, which require bigger checks (Khatcherian, 2022). Yet, among the 10 companies in our survey still actively seeking financing, 6 identified equity as their primary funding source, with strategic investments as the only meaningful alternative, and none reported pursuing project- or blended-finance structures.

Another major underlying barrier is the lack of experience, robust data,



Source: Prime Coalition

Technology Scale Up Process

“The financial models presented by these startups are often **incomplete**. Typically, the analysis consists merely of a simple spreadsheet with basic inputs to calculate margin and profit, which is not up to institutional investor quality."

and case studies, a challenge affecting both investors and entrepreneurs, as well as other risk dimensions in different ways. Climate FOAK projects lack historical performance records (True North Institute, 2025). Therefore, government grant programs struggle to audit and evaluate FOAK applications, and investors lack clear guidelines or benchmarks for applying appropriate metrics to assess the growth potential of climate tech companies (Endeavor, 2022). The few growth funds dedicated to investing in climate tech facilities lack sufficient success stories beyond Series B, making it difficult to select the right investments (Endeavor, 2022). Without reliable data, investors and governments face significant Prime

uncertainty around timelines, costs, and performance, which leads to gaps between expected and actual project metrics and results in cost overruns of 15%–20% - considerably higher than the 5%–10% total cost contingency considered reasonable for steady-state projects (Khatcherian, 2022).

This knowledge gap is not merely observed from the outside – it is the obstacle most acutely felt by founders themselves. Of the 18 climate FOAK companies surveyed, 56% identified 'lack of understanding from funders' as a primary obstacle to securing financing, making it the most cited challenge, ranking above high perceived technological risk (44%) and regulatory barriers (28%).

At the same time, startups themselves often lack the resources or expertise to model credible development plans that meet institutional standards. Some fail to calculate or clearly present critical metrics, further undermining investor confidence. As one of the investors we interviewed mentioned

> *“The financial models presented by these startups are often **incomplete**. Typically, the analysis consists merely of a simple spreadsheet with basic inputs to calculate margin and profit, which is not up to institutional investor quality."*

This challenge is compounded by the high costs associated with feasibility and engineering studies for early-stage companies. The lack of benchmarks makes it challenging for both startups and investors to assess risk and evaluate project viability.

All these factors make governmental support crucial for project derisking and, at times, dependent on government policy. However, almost all our interviewees mentioned that reliance on government funding introduces its own barriers. Political changes, especially in recent years, and moreover since politicizing climate technologies, result in high instability, creating long-term uncertainty for business models. While startups, and small teams especially, may struggle to navigate bureaucratic hurdles and complex application processes. Cutbacks in public funding programs, particularly when politically motivated, can collapse financing pipelines that startups have structured, often with little warning and no viable alternative capital source (True North Institute, 2025).

C.2. Project Development, Integration, and Management

These are risks associated with the existence of processes and capabilities to successfully and consistently execute projects using the technology solution, all within substantial budget and timeline constraints.

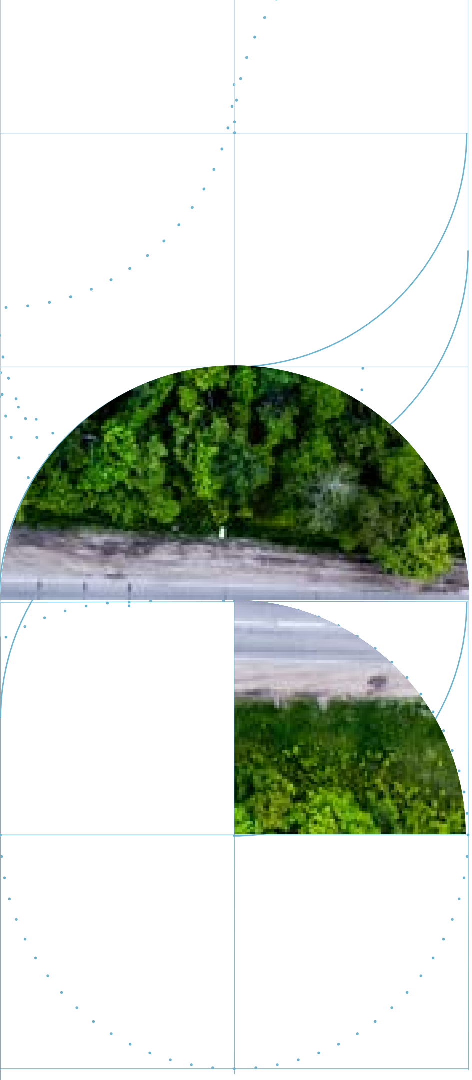
The shortage of qualified workers with experience in climate-technology EPC workflows reduces the quality and accuracy of project planning and execution. This immature ecosystem, lacking operational experts, is a major bottleneck to scaling (Khatcherian, 2022). These knowledge and experience gaps are discussed in other sections as well, as their effects ripple across multiple dimensions of the scale-up process.

83% of the 18 climate FOAK companies surveyed reported significant project delays, with 44% experiencing disruptions of 12 months or more.

In addition, the mindset shift a company must go through to develop a large-scale project is a challenging phase. The development stage imposes a fundamentally different operational rhythm than R&D. Where early-stage work tolerates iteration and ambiguity, FOAK deployment demands precision, sequencing, and the ability to coordinate complex interdependencies across engineering, procurement, and construction simultaneously. While some entrepreneurs prefer slow-scaling models, in many cases, derisking requires large-scale deployment from the outset (Mkhize, 2023). Tesla is an example of such rapid development. If it had not constructed its Nevada Gigafactory in 2014, its prices could not have been competitive (Van den Steen, 2013). In another example, LanzaTech constructed 3 commercial facilities in 4 years, as detailed in a dedicated case study spotlight.

Although climate-tech scale-up processes are often compared to med-tech roadmaps (Sachse & Kapsis, 2024; Wiese, Yale Clean Energy Forum, 2022), a significant difference lies in the absence of neutral and professional tools to plan the growth pathways of different climate technologies. This makes climate-tech FOAKs uniquely challenging.

Project delays are among the most consequential and least anticipated challenges of the FOAK stage - and their causes are rarely confined to a single domain. Delays stemming from permitting, supply chain disruptions, workforce gaps, or financing shortfalls compound, creating cascading effects that are far more disruptive than any single setback in isolation. The scale of this challenge is well documented: in the European Union, new battery gigafactories have experienced start-of-production delays averaging over 10 months (Granskog et al., 2024). Our own primary research reflects a similar reality - 83% of the 18 climate FOAK companies surveyed reported significant project delays, with 44% experiencing disruptions of 12 months or more. The impact of these delays extends well beyond finance: they force continuous reprioritization across the entire organization and its partner network, strain operational capacity, and



human-capital structures. Therefore, project development, integration, and management are directly connected to the workforce dimension, as well as to material sourcing and license-to-operate risks.

C.3. Infrastructure

Infrastructure risks refer to the large-scale physical systems that must be in place to support, enable, or facilitate full-scale deployment (e.g., pipelines, transmission lines, roads, and bridges). This dimension highlights the differences in challenges between the first large production site and the first site demonstrating the technology.

A significant challenge arises if broad deployment requires additional material investments in new large-scale infrastructure or if the pathway to necessary infrastructure remains unclear. For example, offshore wind sites in the U.S. face difficulties due to a lack of Jones Act-compliant.[2]In some cases, deploying a FOAK requires the construction of entirely new infrastructure, whereas in others, existing infrastructure can be adapted to meet project needs. When new infrastructure is essential, development cannot always proceed incrementally. Instead, the facility must often be established at full scale from inception.

In addition, a key challenge, as demonstrated in the infrastructure dimension, is the limited availability of accessible "test beds" or dedicated facilities for developing and validating the planned processes, which can lead to modifications and adjustments during the development stage (Sefton et al., 2020).

As we noted, many risk dimensions interlink and affect one another. Infrastructure is one of the most converging dimensions, directly connected to ease vs. complexity of implementation and use, (skilled) workforce, policy environment, permitting & siting, and community perception. These are further discussed in the relevant sections.

FOAK companies often face a critical trade-off: scale aggressively to secure supply chain leverage, or move cautiously and risk being deprioritized by suppliers.

C.4. Manufacturing & Supply Chain

Manufacturing and supply chain risks are associated with material sourcing, processing methods, and the reliability and integration of third-party vendors. FOAK deployments often require the creation of new manufacturing processes or supply chain components that are not currently in place, or that may overwhelm existing supply chain capacities.

Geographic factors may impose challenges. While proximity to suppliers and manufacturers can be particularly critical in the early phases of FOAK deployment by enabling faster problem resolution and more effective quality assurance (Sefton et al., 2020), proximity to the target market will increase long-term profitability.

Large facilities face high operating costs. When these are combined with rapidly evolving regulations and fluctuating global demand, planning manufacturing and supply chain operations becomes significantly more challenging. Shifting climate-related policies and trade dynamics complicate both the procurement of critical feedstocks and the distribution of products to international markets.

For instance, a startup targeting European customers may prefer to

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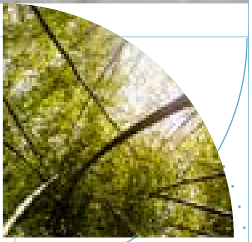
[2] The Jones Act is a federal law requiring that goods shipped between US ports be transported in ships built, owned, and operated by US citizens or permanent residents

Source: Northvolt

Geopolitical tensions and energy security priorities, FOAK deployment needs to handle rapidly fragmenting global systems.

produce locally, yet the availability and cost of key inputs or import tariffs may push production decisions in other directions. Unlike digital or software-based firms, climate FOAKs lack the same level of agility to adapt quickly to regulatory change, making the very long-term planning particularly difficult. Startups reported shortages of key components manufactured almost exclusively in China, which significantly affected their growth (Endeavor, 2022).

New supply challenges include not only global trade wars but also broader geopolitical factors, accelerating the global shift toward de-globalization and tightening domestic energy security strategies. These developments present an opportunity for climate technology, reframed from a purely environmental initiative to a national security and energy independence imperative (WEF & BCG, 2025). The fallout from Russia's invasion of Ukraine exposed the extreme economic vulnerability of relying on external energy suppliers, prompting European countries to rapidly prioritize alternative supply chains and domestic renewable energy capacity (Wan et al., 2022). Yet it also created challenges and barriers for international trade, both for feedstock supply, as seen, for example, in the EU Industrial Accelerator Act (detailed on the relevant spotlight), and for the export of products in dynamic business environments, which can affect delivered cost challenges.



Lastly, suppliers often prioritize high-volume orders from established players over emerging startups, which can result in longer delays and higher premiums. This reality heavily influences the strategic pacing of deployment: companies may choose to accept higher technical risks by scaling up faster, specifically to generate the order volumes required to gain leverage over suppliers and secure a viable supply chain. This approach is exemplified by Stegra (formerly H2 Green Steel), which launched immediately with a multi-billion Euro commercial facility to compel 'upstream and downstream actors to buy in on the success of the company' (Algers, 2024; Thyssenkrupp nucera, 2024), a strategy echoing the Tesla example mentioned in section C.2. Project Development, Integration, and Management.

However, this aggressive scaling carries existential risk if execution falters. Northvolt provides a counter-example: despite securing massive order volumes, their inability to ramp up production yield led to missed deliveries, the cancellation of a €2 billion contract with BMW, and ultimately bankruptcy in 2025 (CarbonCredits.com, 2025).

C.5. Materials Sourcing

These are risks associated with the availability of critical materials required by the FOAK (e.g., rare-earth and other limited-supply materials), both during technology development and for operationalization. This includes not only rare or expensive but also operationally demanding materials that require specialized handling due to toxicity, instability (e.g., cryogenic hydrogen), or high variability (e.g., inconsistent biomass waste). Such challenges might make the facility's production cycle economically unsustainable and should therefore be thoroughly researched and factored into the project's design from the outset.

These challenges are especially common in materials with limited supply relative to demand, those difficult to obtain, or those subject to geopolitical risks or high production costs, as mentioned in the above dimensions. Startups often struggle to find reliable suppliers and may not be prioritized as small customers, especially when ordering in low volumes. This can lead to higher costs per part and lower prioritization by suppliers during more challenging times, due to a lack of economies of scale, which impacts the pricing strategy and risks volume growth. Moreover, when a particular technology attracts heightened attention, multiple firms may simultaneously compete for the same feedstock, creating upward pressure on prices (Sefton et al., 2020).

China controls 80% of global lithium and 85% of the world's cobalt supply.

As mentioned in section C.4. Manufacturing & Supply Chain, geopolitical shifts significantly amplify these sourcing challenges. Geographic concentration in the production of critical materials creates structural dependencies that can restrict companies' physical access to these materials when operating outside specific geographies (WEF & BCG, 2025; Wan et al., 2022; Net Zero Insights, 2025). To illustrate, China controls 80% of global lithium production (Carbon Collective, 2026). Furthermore, about 85% of the world's cobalt supply is processed in Chinese refineries, and Chinese firms are expanding heavily into nickel extraction to maintain their market control. For FOAK developers, reliance on materials supplied by a limited number of geographies can create a significant sourcing risk as international balance shifts and alternative suppliers do not exist.

Reliance on scarce materials, coupled with global shortages and price volatility, can delay production and erode customer trust, as one of the startups we interviewed, with facilities in distant locations in Latin America, highlighted. Another example is Northvolt's project, which faced hurdles due to constrained access to Lithium and Nickel, which, alongside other strategic mistakes, led to the cancellation of a €2 billion contract with BMW (True North Institute, 2025).

C.6. Workforce

Workforce risks are associated with the human capital and capabilities required to design, produce, install, maintain, and operate the technology solution at scale. FOAK projects often require highly experienced workers with niche or high-demand skill sets, such as specialized electricians or engineers. This can lead to labor shortages and high labor costs, resulting in delays and reduced returns (Freeman, 2024). Workforce has been mentioned above as a factor affecting other risk dimensions and through other entities; however, here we focus on the FOAK's workforce as a stand-alone risk.

First, in a broader context, the skill profile of employees in a company developing a FOAK project differs significantly from that of a startup focused on R&D. Many interviewees highlighted the transition founders need to go through, shifting from an R&D-led scope ("move fast and break things") to development and operations skills. The “scrappy” and “hungry” attitude often associated with founders may be inadequate for FOAK projects, which demand a more thorough and prudent approach and, in some cases, experienced leadership to guide execution.

Therefore, the skill set needed for laboratory work is not the same as that required to deliver large-scale infrastructure projects, making the transition challenging for many teams. If the shift is too difficult for existing teams, companies may need to restructure or hire new teams as the focus and required expertise evolve (Mkhize, 2023). Not only does the company need to hire new employees, but it also must adjust its strategy to accommodate these changes (Sefton et al., 2020). We will elaborate on this shift further in the recommendations section; however, the transition itself is a challenge, as timing and adaptation to a new organizational culture are critical for a smooth scale-up. For complex projects, there can be cultural integration challenges between teams, such as "marrying the culture of power engineers with that of chemical engineers" (Khatcherian, 2022).

Historical examples illustrate this challenge. Biofuel startups have, in several cases, shown a tendency to hire many researchers but few operations experts, leading to failures due to logistics and coordination rather than pure scientific problems. For example, KiOR, a biofuel company that filed for bankruptcy in 2014, had a "preponderance of lab researchers with PhDs and a dearth of people with technical, operational experience" (Mohorčich, 2019).

> KiOR, a biofuel company that filed for bankruptcy in 2014, had a "preponderance of lab researchers with PhDs and a dearth of people with technical, operational experience".

Hiring and training the new teams is another barrier to growth. FOAK startups face intense competition for skilled workers from larger, more established, and stable companies. These traditional companies can offer higher salaries, more benefits, and greater job security, making it harder for startups to attract and retain the experienced professionals they need.

Additionally, once moving from a lab-scale project to FOAK, the company's core might relocate to a different location closer to the FOAK's physical site. Siting decisions are critical for accessing a deep technical labor pool. Consequently, companies that locate in areas with insufficient qualified personnel may end up hiring unvetted individuals (Mohorčich, 2019). In addition, because FOAK projects rely on innovative technologies, companies are forced to train their own workforce from scratch. Once these employees are qualified, they often become prime targets for competitors seeking ready-made expertise.

Nevertheless, according to Endeavor’s survey, founders ranked the availability of managers as a greater obstacle than technical talent, though both remain challenging to acquire and retain. Small talent pools, heavy competition, and high salary expectations are the main barriers for hiring managers. Founders also noted that startups tend to attract younger professionals, making it harder to recruit mid-career managers. Companies in fast-growing sectors, such as energy storage, face this challenge more acutely, as the competition for experienced talent among entrepreneurial companies is increasing faster than the supply (Endeavor, 2022).

The workforce challenge is not limited to individual companies but is also a macro-level issue. There is a shortage of qualified project developers and, more generally, industry experts. The broader ecosystem around innovative

Source: Form Energy

Startups cannot treat regulatory and policy issues as external constraints; they must manage them as strategically and proactively as they do financing, technology, or market development.

climate solutions often lacks experienced developers with expertise in evaluating technology and market risks, as well as operational experts. Furthermore, not only in-house positions but also support functions in the innovation ecosystem may lack adequate production competence or guidance for startups, highlighting a perceived need for experienced production coaches (Sefton et al., 2020). Indeed, founders report that finding mentors with relevant experience is difficult, often requiring them to rely on networks in the broader tech sector (Endeavor, 2022).

D. License to Operate

As the final risk area in this report, license to operate captures the conditions that ultimately determine whether a climate FOAK technology can move from design to deployment. After examining the technological, market, and organizational risks in the previous chapters, this section shifts focus to the broader ecosystem in which innovation must prove itself legitimate and permissible.

Unlike in mature sectors, where regulation and policy provide relatively stable background conditions, climate-tech's ecosystem, economy, and rulebook are still being written and, in recent years, have proven to be quite volatile. As a result, startups cannot treat regulatory and policy issues as external constraints; they must manage them as strategically and proactively as they do financing, technology, or market development. Moreover, as emphasized in many interviews, the change will not come from governments alone; startups and developers must engage directly with regulators, participate in policy design, and often push for the very frameworks that will enable their technologies to exist. In doing so, they evolve from passive rule-takers into active co-architects of the transition.

D.1. Regulatory Environment

Regulatory environment risks relate to the regulatory and permitting frameworks governing FOAK deployment, including the clarity, consistency, and efficiency of the processes required to bring innovative climate technologies to market. For FOAK climate technologies, regulation is a double-edged sword – it provides the enabling conditions for innovation implementation by pushing the market to adapt but can also delay or prevent deployment when policies are unclear or not adapted to novel solutions. This absence of clear, harmonized, and predictable rules, standards, and procedures creates uncertainty that can delay or even prevent deployment, making regulatory readiness a critical dimension of License to Operate.

Permitting delays can extend renewable energy projects by up to 9 years.

The 2025 Annual Knowledge Sharing Report of the Innovation Fund highlights that one of the most significant barriers for FOAK projects is the lack of standardization in the permitting and approval process (Innovation Fund, 2025). Each project must chart its own regulatory path, as there is no consistent framework or predefined route to authorization. This lack of predictability is compounded by fragmented regulatory authority, with overlapping responsibilities between federal, regional, and local agencies (OECD/KDI, 2021). For example, while one authority might oversee Environmental Impact Assessments (EIA), another may handle energy grid integration or safety compliance, often without coordination. The result is confusion, inconsistent rulings, and lengthy delays (Innovation Fund, 2025). The slow pace of public institutions compounds the problem: as with regulation, policy actors often lag behind technological innovation, leaving emerging solutions without clear eligibility criteria or long-term market signals (UNDP, 2025).

This regulatory fragmentation is further amplified at the international level, where the lack of harmonized standards and differing interpretations of rules across jurisdictions force companies to adapt their business models and compliance strategies in every market (OECD, 2025).

These challenges are particularly acute for CO_2 infrastructure and storage projects, which operate within a fragmented regulatory landscape where national interpretations and permitting standards vary widely. Existing frameworks, designed for conventional energy markets, are ill-suited to the unique characteristics of CO_2 capture, transport, and storage, underscoring the need for harmonized, future-proof regulation to enable cross-border deployment and investor confidence (Zero Emissions Platform, 2025).

Moreover, existing permitting procedures develop slowly and are not designed for novel technologies, forcing developers to adapt outdated rules to new systems (UNDP, 2025; OECD, 2025). According to a recent report, permitting delays can extend renewable energy projects by up to 9 years (World Economic Forum & Boston Consulting Group, 2025). As FOAK projects often combine multiple technologies, each governed by different regulatory regimes, developers must navigate separate approval processes that were never intended to operate in tandem. Hydrogen developers, for instance, frequently report having to apply regulations designed for unrelated industries, as there is still no dedicated legislative framework for hydrogen production and storage in many markets (Innovation Fund, 2025). This not only increases administrative complexity but also raises compliance costs and uncertainty about the long-term legality of the project.

50% of companies surveyed identified regulatory advisory support as their most cited resource gap.

Regulatory barriers on the road to FOAK aren't a problem specific to a country or region, but a global one. Nearly half (44%) of interviewees for the Innovation Fund's report noted that their local or national agencies lacked the technical knowledge or human resources to evaluate innovative projects. Because FOAK technologies are inherently unprecedented, authorities struggle to interpret existing standards or assess risks accurately, leading to conservative decision-making and slow progress.

LanzaTech's experience exemplifies this challenge. As their technology did not fit within existing European regulatory categories, they could not wait for policy to evolve and had to actively work with policymakers to create the conditions necessary for deployment. Over several years, the company collaborated closely with regulators to define new standards and compliance pathways, effectively "pushing regulation forward" to accommodate innovation. This case demonstrates that regulatory adaptation often depends on proactive engagement by project developers rather than on institutional readiness.

Yet this proactive engagement is easier to prescribe than to practice. Among the 18 companies surveyed, regulatory advisory support was the most cited resource gap, identified by 50% of respondents, suggesting that, while founders understand the importance of regulatory navigation, access to the expertise needed to navigate it effectively remains limited.

In addition, interviews revealed that many FOAK failures can be traced to leadership's underestimation of regulatory impact. Academic or technically oriented founders often overlook the complexity and centrality of permitting, resulting in severe project delays, unexpected costs, or complete stagnation once the technology reaches scale. In our company survey, unresolved regulatory barriers were cited as the second most common cause of delays after lack of funding. This lack of regulatory foresight underscores the importance of integrating policy expertise early in the project lifecycle through dedicated teams overseeing the company's and FOAK's regulatory aspects.

Altogether, slow-moving and outdated regulatory frameworks, coupled with the fragmented web of authorities and rules governing complex technologies, create major obstacles for FOAK deployment. Overcoming these barriers requires early attention, specialized expertise, and creative, proactive engagement with regulators to adapt existing systems to innovation.

D.2. Policy environment

Policy environment risks are those related to the broader policy landscape that shapes the feasibility and stability of FOAK climate-tech deployment. These include the presence and reliability of supportive policies, institutional capacity to implement them, and the predictability of government incentives and targets. A favorable policy environment can accelerate technology uptake and investment confidence. Conversely, policy uncertainty and administrative inefficiency can deter investors and delay projects.

Many governments lack clear, long-term laws that promote climate-tech innovation. Political volatility, leading to inconsistent incentive schemes such as subsidies or tax credits, creates uncertainty for both investors and developers, who base long-term economic plans on them. Generous programs can be highly effective in stimulating early markets, but if withdrawn abruptly or redesigned after political turnover, they can collapse financing pipelines and erode trust (Mkhize, 2023). The abrupt suspension of U.S. DOE programs at the onset of the current U.S. Federal administration, contrasted with sustained industrial policy in China, illustrates how political shifts can determine whether a technology ecosystem scales or stalls (True North Institute, 2025).

Beyond instability, bureaucratic hurdles, and limited institutional capacity, these factors hinder access to existing public schemes. Startups often face complex, lengthy applications and fragmented administrative requirements, which prolong timelines and discourage participation (Innovation Fund, 2025). These obstacles are particularly burdensome for small firms with limited resources and policy expertise. This challenge is closely related to the Regulatory Environment discussed above, as both policy incentives and regulatory approvals are hampered by the same lack of institutional readiness.

Altogether, FOAK developers operate in a volatile and fragmented policy landscape where shifting incentives, political turnover, and administrative bottlenecks can abruptly alter project viability. Building stable, transparent, and coordinated policy frameworks, coupled with capable institutions to implement them, is critical to reducing perceived risk and enabling sustained climate-tech deployment.

SPOTLIGHT
EU Industrial Accelerator Act Proposal

While not FOAK-specific, the IAA signals a policy environment increasingly designed to enable, and geographically anchor, FOAK deployment.

On March 4th, 2026, the European Commission adopted a legislative proposal of the Industrial Accelerator Act (IAA). The IAA regulatory framework is intended to accelerate industrial decarbonization and infrastructure deployment in strategic sectors, especially those linked to the net-zero transition, within the European Union (EU).

The proposed Act represents a shift in the EU's industrial policy toward actively supporting domestic manufacturing and accelerating the deployment of low-carbon technologies. The proposal is structured around three main pillars: permitting simplification, the creation of "Made in Europe" lead markets, and new conditions on foreign investment in strategic sectors. First, the Act introduces a streamlined permitting framework based on a single digital access point and a "one project–one procedure" principle, with approval timelines of up to 18 months for energy-intensive and cleantech manufacturing projects. This approach is intended to reduce regulatory bottlenecks that often delay large industrial and infrastructure developments. Second, the Act establishes "Made in Europe" and low-carbon preferences in public procurement and public support schemes, particularly in sectors such as steel, cement, aluminium, automotive components, and net-zero technologies. Third, it introduces conditions for large foreign investments in strategic sectors exceeding €100 million, requiring measurable contributions to employment, innovation, and supply-chain development within the EU (European Commission, 2026). As a result, non-EU companies seeking to enter or expand in these sectors of the European market will face new compliance requirements.

Although the IAA does not explicitly target FOAK technologies, its mechanisms are directly relevant to their deployment: streamlined permitting reduces one of the most significant timeline risks at the FOAK stage, domestic procurement preferences create early demand signals that improve offtake visibility, and supply chain conditionality strengthens the industrial base on which FOAK facilities depend. For climate-tech developers targeting the European market, the IAA represents both a regulatory tailwind and a strategic signal – the policy environment is shifting in ways that reward early positioning.

D.3. Permitting & siting

Permitting and siting risks are associated with obtaining the necessary approvals and permissions to construct and operate FOAK facilities. While the regulatory environment governs the general compliance of the process and product category, permitting and siting focus specifically on the authorizations required for the operation of the physical site and land use. This includes the time, cost, and uncertainty of navigating complex and fragmented permitting systems. Because these projects introduce novel technologies or processes that often fall outside existing regulatory categories, they face particularly cumbersome and unpredictable approval pathways.

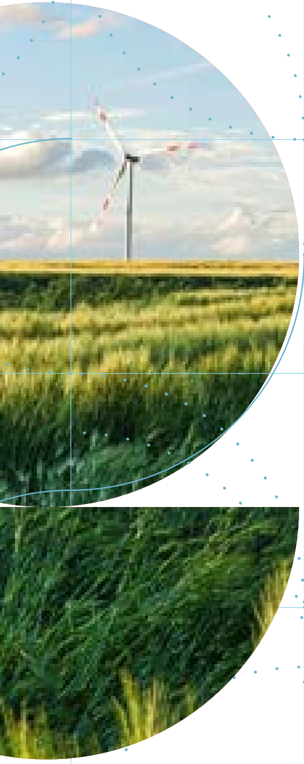
Permitting processes are consistently identified as one of the longest and most uncertain phases of the FOAK journey. Developers face lengthy procedures, often stretching several years, during which capital is locked and investor confidence erodes. In many jurisdictions, rules and requirements vary not only across countries but also within regions of the same country, resulting in inconsistent expectations, duplicative documentation, and conflicting interpretations of standards (Innovation Fund, 2025; OECD/KDI, 2021). This fragmentation forces developers to restart or rework submissions for each locality, adding cost and administrative burden as plans change or develop.

A key structural problem is the sequential and interdependent nature of approvals. Many permits, such as EIA, land-use authorizations, and safety certifications, must be completed one after another rather than in parallel. Each stage can trigger additional reviews or appeals, creating long bottlenecks that delay construction and financing milestones (ZEP, 2025; Innovation Fund, 2025). In addition, the absence of coordinated approval frameworks, with no unified timeline, lead agency, or consolidated decision structure, means that multiple authorities evaluate the same project independently, often with little communication or shared responsibility (OECD, 2025).

This institutional fragmentation leads to what many developers describe as institutional overload. Agencies dedicate significant resources to partial reviews or limited-scope approvals without certainty that the entire project will ever advance, resulting in regulatory fatigue and inconsistent decision-making. For FOAK technologies, which may involve novel safety or environmental profiles, the lack of clear precedents further slows down evaluations as each authority conducts its own risk assessment from first principles.

D.4. Environment and safety

These are risks associated with the environmental and occupational safety dimensions of FOAK development, including compliance with unfamiliar regulatory requirements, adaptation of safety standards to novel processes, and management of potential environmental and health impacts during construction and operation. These challenges are intensified by the fact that FOAK technologies often involve new chemical, thermal, or mechanical conditions for which no established regulatory



precedent or industrial experience exists.

EIAs are among the most significant environmental hurdles for FOAKs. When technologies are unfamiliar to regulators, the assessment process becomes slower, more uncertain, and highly iterative. Authorities frequently lack reference data or benchmarks to evaluate potential impacts, leading to multiple requests for additional studies and expert opinions before approval. As multiple interviewees noted, this lack of precedent turns EIAs into open-ended procedures that extend permitting timelines and increase project costs.

Beyond environmental review, FOAK projects face major process-safety challenges. Because many operate under untested pressure, temperature, or chemical conditions, conventional design codes and safety standards often do not apply (CREO, 2024). Developers must therefore create tailored safety protocols and risk assessments covering containment integrity, equipment reliability, and emergency response from first principles. This need to define new safety regimes also exposes projects to higher insurance and certification costs and longer commissioning periods.

At the company level, the absence of experienced environmental, health, and safety (EHS) teams magnifies the risk. The Hardware Start-ups in the Scale-up Process of Production study found that many hardware scale-ups entering production lack personnel with industrial safety expertise, making the ramp-up phase especially vulnerable to accidents, operational errors, and quality failures (Sefton et al., 2020). Training, procedures, and monitoring systems must often be developed from scratch, consuming time and resources that could otherwise be used for deployment.

Finally, as many climate technologies connect to existing energy systems, they must integrate with external infrastructures such as energy grids, CO_2 transport networks, or hydrogen pipelines. As such, they face additional "firewalls" in environmental and safety regulations. These external interfaces require separate approvals for hazardous materials handling, high-pressure systems, or potential emissions, each governed by distinct agencies and compliance codes (Innovation Fund, 2025; ZEP, 2025; CREO, 2024).

D.5. Community Perception

Community perception risks relate to public acceptance and the social legitimacy of FOAK climate technologies, which, in turn, significantly influence permitting timelines, political support, and investor confidence. Because FOAK projects are novel, they face heightened scrutiny and social resistance, especially when perceived as risky or potentially disruptive to the local environment and quality of life.

Public concern over industrial risks and environmental impacts, including noise, emissions, and land use, frequently leads to opposition or demands for stricter environmental requirements. Both the OECD Regulatory Policy Outlook (2025) and the Innovation Fund Knowledge Sharing Report (2025) emphasize that early, transparent stakeholder engagement is critical to mitigating these tensions between environmental, safety, and social objectives. When communities are not informed or involved early, skepticism grows, particularly around the safety and fairness of locating novel technologies near residential or agricultural areas.

Because FOAK technologies are unfamiliar, communities often lack trust that they are safe, reliable, or beneficial. Even projects designed to reduce emissions or support green transitions are sometimes met with the same resistance as traditional heavy industry (Innovation Fund, 2025). This skepticism is intensified when projects involve hazardous or poorly understood processes, such as carbon capture, hydrogen production, or synthetic fuels. Fears of CO_2 leaks, explosions, or contamination create social opposition and political hesitation, underscoring the need for transparent monitoring, clear liability frameworks, and open communication to build acceptance (ZEP, 2025).

Even environmentally positive projects face adverse landholder and community sentiment when local costs such as land occupation, noise, or visual disturbance are immediate and tangible, while the broader environmental benefits are abstract or long-term (OECD, 2025). This asymmetry between local costs and global benefits echoes findings from Barriers to the Timely Deployment of Climate Infrastructure (Khatcherian, 2022), which observes that communities are more likely to oppose projects when they bear concentrated impacts but receive diffuse benefits.

In summary, the road to FOAK is paved with a medley of interconnected and systemic challenges. Ventures must simultaneously validate their value proposition against incumbents, cultivate market acceptance where demand is often nascent, secure the resource maturity: financial, physical, and human needed for scale, and navigate the complex license to operate landscape of regulations and public trust.

With this diagnostic map established, the following section turns to the strategies required to navigate these challenges, detailing how successful companies and ecosystem actors can proactively derisk deployment and bridge the gap to commercialization. China represents a distinctive institutional model in which FOAK deployment is coordinated through state-owned enterprises (SOEs), centralized industrial planning, and long-term national policy frameworks, rather than through market-led project development. Although some of its central elements may not necessarily be relevant to market-led ecosystems, given that many dominant players promoting FOAK development are SOEs aligned with a central policy approach, China's model could shed light on some of the key structures and processes that can play a prominent role in shaping this ecosystem.

SPOTLIGHT

China: Institutional Structures and the Role of State-Owned Enterprises (SOEs) in FOAK Deployment

China's FOAK projects are managed in fully coordinated systems.

Carbon capture, utilization, and storage (CCUS) and advanced nuclear power[3] are consistently identified in the literature as strategic priorities within China's decarbonization and industrial policy framework, and they provide observable evidence of how the state structures the transition from research and demonstration to full commercial operation. We have identified that the main engines driving this growth are SOEs leading deployment processes, centralized project management systems enabling the coordination of complex infrastructure projects, and knowledge management mechanisms spanning from the earliest stages of technology development to broad commercialization. The last strategy generates operational learning and translates it into standardized technological designs, enabling replication through fleet-level deployment.

First and foremost, unlike international FOAK projects, which are usually developed in fragmented institutional and financial environments, China's FOAK projects are managed in fully coordinated systems where there is no clear separation between the financing organization, the regulator, the clients, and the supplier. SOEs function simultaneously as technology developers, project developers, asset owners, and deployment platforms. Combining these roles within a single institutional framework reduces coordination barriers between technology development and industrial deployment. As a result, once a technology is demonstrated, it has the financial and operational resources to be rapidly replicated across multiple projects, enabling China to commercialize FOAK technologies faster than many market-driven systems. China's FOAK deployment model also relies on a distinctive industrial workforce structure organized around SOEs networks. In both the CCUS and nuclear sectors, workforce collaboration is done through a specialized state-owned subsidiary and a vast network of industrial contractors and manufacturers, all operating under the centralized leadership of a parent SOE. These are rarely independent private firms; they are usually organized within a multi-layered state hierarchy (Bongers, 2024; Xing et al., 2023).

The SOEs also have the unique capability to lead deployment because they can leverage extensive historical state-controlled data, such as from oil and gas exploration, now applied to identifying suitable CO2 storage sites for the CCUS projects (Mitterrutzner et al., 2026). In addition, they have state-backed financial resources to offset the high-risk premiums associated with FOAK projects. As a result, China has structured FOAK development through coordinated state intervention that reduces uncertainty, mobilizes capital, and accelerates scale-up (Bongers, 2024; CGNPC, 2023). SOEs

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[3] The term "advanced nuclear power" refers to the pressurized water reactor HPR1000's classification as a Generation III reactor with enhanced active and passive safety features and safety performance indicators that meet or exceed contemporary international third-generation standards (CGN, 2023; Xing et al., 2023).

receive substantial state-backed R&D investment and can develop and deploy technologies across multiple Technology Readiness Levels (TRLs), from early demonstration to full-scale industrial deployment (Bongers, 2024).

The HPR1000 project illustrates how SOE governance operates in practice, with a single SOE taking the lead for the entire project and coordinating large-scale construction and manufacturing companies. The SOE has a whole-life-cycle management system built on a Project Management Information System (ProMIS) platform. ProMIS[4] was developed by SOE China Nuclear Power Engineering Co., Ltd. to address coordination challenges for the world's first HPR1000 reactor, the Fuqing Unit 5 project, by consolidating all major project functions into a single digital management platform (Xing et al., 2023).

The research institutes' learning process help coordinate and examine learning while operational facilities generate the data.

The system allows information from the design phase to flow directly into procurement and construction, overcoming the challenges posed by projects involving thousands of suppliers, contractors, and teams coordinating interdependent tasks. This digital flow avoids delays typical of transferring data across separate systems. For example, project phases that are usually sequential can proceed in parallel, and procurement decisions and construction planning could be made earlier, while project managers could supervise progress and fix technical conflicts in real time. Therefore, real-time information sharing and integration on a central platform significantly reduced the time needed to move from engineering design to physical construction (Xing et al., 2023).

Beyond project-level coordination mechanisms such as ProMIS, China has also developed institutional structures that bridge the gap between early-stage research and full-scale industrial deployment. China has developed strong institutional and technological mechanisms to bridge this stage in both nuclear energy and CCUS development, as demonstration facilities operate as industrial experimentation platforms, rather than serving only as proof-of-concept projects. As part of this mechanism, state-owned research institutes function as operational hubs. The research institutes' learning process normally occurs through networks that combine SOEs, universities, and demonstration projects. It helps coordinate and examine learning while operational facilities generate the data (Bongers, 2024; Xing et al., 2023). For example, China's CCUS strategy has relied on more than 100 demonstration projects at various scales. This approach allows engineers and researchers to progressively improve technologies through learning-by-doing and system integration (Bongers, 2024). China has also developed comprehensive systems for technology-related standardization. For example, the initial HPR1000 demonstration reactor, Fuqing Unit 5, served as the primary testing ground for the integrated technological system. Through this project, digital R&D platforms, testing infrastructure, and simulation systems were established to support further technological refinement and verification. Following the unit's demonstration of reliable performance, the knowledge generated was consolidated into a comprehensive standardization framework covering the full lifecycle of nuclear power plants, from design and manufacturing to construction and operation. The standardization system aims to enable China to achieve an industrial-scale deployment through repetition, thereby

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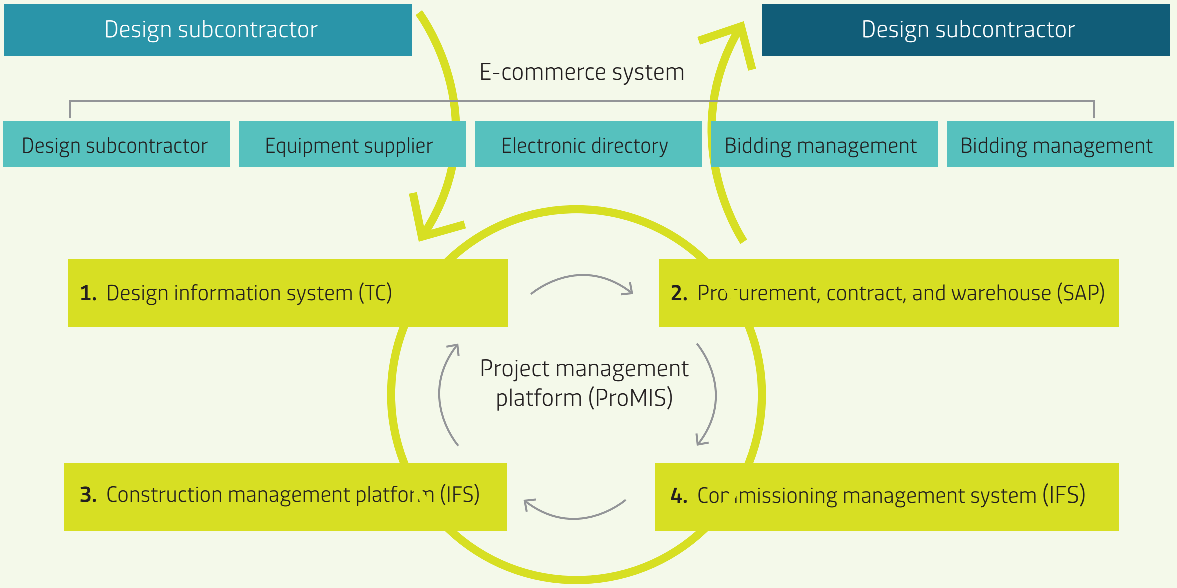
[4] ProMIS is a central digital system that integrates all project information and management functions into a single platform to support the complex organization of third-generation nuclear power projects (Xing et al., 2023).



Source: Xing et al., 2023

ProMIS

reducing uncertainty, CAPEX, and engineering risk (Xing et al., 2023). These institutional arrangements support a wider, continuous process of technological improvement across multiple projects, sometimes described as fleet-wide innovation. China is targeting this to improve performance and reduce costs within the shortest possible timeframe (Bongers, 2024).

At the national level, both CCUS and nuclear energy support China's "Dual Carbon" goals: peaking emissions by 2030 and reaching carbon neutrality by 2060 (The State Council of the People's Republic of China, 2025). These goals are supported by operational plans that link the overarching national climate policy to several sector-specific action plans (The State Council of the People's Republic of China, 2025). CCUS is incorporated into sectoral strategies across heavy industry, energy production, and regional decarbonization planning (Bongers, 2024). While nuclear power is integrated into the energy system, low-carbon electricity, and national decarbonization planning (CGNPC, 2023). In line with the shift toward de-globalization and energy independence, China aims to reduce its dependence on foreign suppliers and improve replicability. Therefore, the SOEs operate within mature domestic industrial supply chains that emphasize local manufacturing and technological "re-innovation" (CGNPC, 2023).

Nevertheless, international cooperation and regulatory recognition also play an important role in supporting China's FOAK technology development and global deployment. These include global climate agreements, such as the Paris Agreement (Mitterrutzner et al., 2026; Lin et al., 2018) and the Sunnylands bilateral agreement between China and the U.S., committing both countries to advance at least 5 large-scale cooperative CCUS projects by 2030 (Bongers, 2024). China also has a long history of bilateral research programs for FOAK development, such as the Australia-China joint coordination group on clean coal technology (Bongers, 2024). China utilizes a comprehensive framework of international safety reviews, utility certifications, and collaborative standard-setting to approve its FOAK projects to the global market, in line with its efforts to become a global technology provider (Bongers, 2024; CGNPC, 2023). For example, in

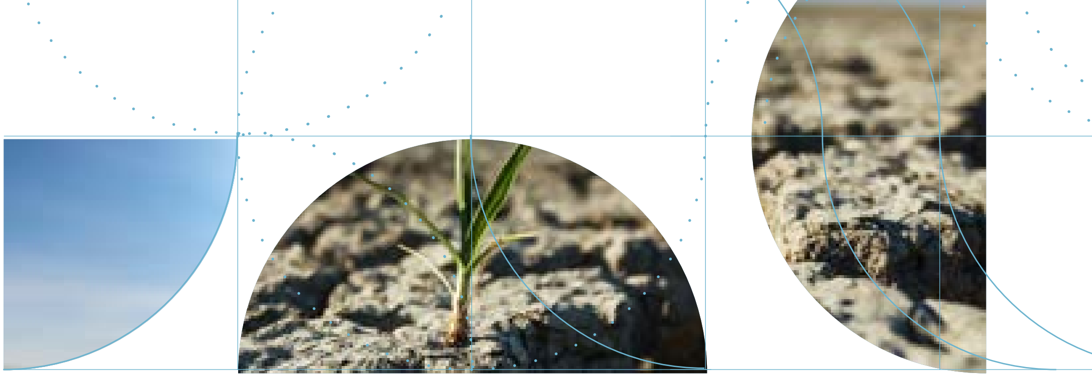
2022, the HPR1000 obtained UK Generic Design Assessment certification, passing rigorous evaluations by the Office for Nuclear Regulation (Environment Agency, 2022; CGNPC, 2023).

These factors and processes allowed China to demonstrate an unusually rapid progression from R&D to full FOAK deployment. In the carbon capture sector, for example, projects such as the 1.5 Mtpa Longdong facility progressed from greenfield development to first CO_2 capture in approximately two years (Bongers, 2024). In the nuclear sector, the centralization and synchronization enabled the HPR1000 (Hualong One) reactor to be completed in 5.7 years. According to Xing et al.(2023), this represented the shortest construction period achieved for the first unit of a third-generation nuclear reactor globally (Xing et al., 2023).

As a whole, China's FOAK development model combines centralized coordination, industrial integration, and structured learning cycles to accelerate the transition from demonstration to large-scale deployment. While the CCUS strategy follows a phased progression toward a broader storage network (Mitterrutzner et al., 2026), the nuclear strategy relies on standardized fleet construction supported by iterative, batch-based technological improvements (CGNPC, 2023). These sector-specific approaches illustrate how China deploys FOAK differently across sectors, selecting strategies that best support national policy objectives while enabling efficient scaling and compliance with international standards.

Key Insights

- State-owned enterprises integrate multiple roles within FOAK deployment, acting simultaneously as technology developers, project managers, asset owners, and deployment platforms.
- Standardization frameworks translate operational learning into replicable industrial designs.
- FOAK deployment strategies are embedded within national industrial and climate policy frameworks, aligning technological development with China's long-term decarbonization goals.
- Government-developed digital management systems support continuous project oversight and coordination.
- State research institutions support the entire development cycle, generating lessons throughout the construction and operation of demonstration facilities.



The Climate FOAK Playbook

The diagnostic map of challenges presented in the previous section illustrates that the "Valley of Death" is not merely a funding gap but a structural mismatch between the agility expected of early-stage innovation and the rigidity of industrial deployment. While the barriers, ranging from workforce shortages to regulatory fragmentation, are systemic, overcoming them requires targeted strategic interventions at the company level.

The following section outlines a "playbook" for climate FOAK success, detailing strategies and tools to navigate the transition from R&D to commercial scale. We will first outline the strategies for the companies involved, followed by a brief overview of key stakeholder strategies. The discussion begins by focusing on the financial architecture needed to support high-risk infrastructure, then moves to the requisite operational and strategic adjustments to deploy capital effectively.

> A primary advantage of a syndicate is that it brings a blend of skills essential for navigating the complex transition from pilot to commercial scale.

Companies

Blended Finance

Blended finance has become the cornerstone mechanism for advancing capital-intensive climate technologies toward commercial scale. Our interviewees had diverse perspectives on many issues, but a broad consensus emerged that no single traditional source of capital can adequately support the high-risk, multi-phase journey of climate innovations, and not strictly for financial reasons.

Blended finance is defined as a hybrid funding model that strategically layers public, private, corporate, and impact-oriented capital to derisk high-impact or early-stage climate technology projects (Granskog et al., 2025; Przadka et al., 2025; Freeman, 2024; True North Institute, 2025). Blended finance addresses the various challenges mentioned earlier. Most directly, it helps address Capital Flow (C.1) challenges to secure adequate financing throughout the scaling process. By using public or concessional funds to absorb early-stage risk, blended finance mobilizes the private investment that would otherwise remain idle (Granskog et al., 2025; Black & Melendez, 2024). Blended finance creates a sequenced capital architecture in which each layer of investors, beginning with public grants, then strategic corporate investment, private equity, and, eventually, project-level debt, performs a distinct risk-transfer function. This structure enables technologies to progress from equity-dominated early phases toward traditional project finance, as operational and revenue risks decline (Granskog et al., 2025; CREO, 2024; Przadka et al., 2025; U.S. DOE, 2024).

Yet, blended finance provides more than capital; a primary advantage of a syndicate[5] is that it brings a blend of skills essential for navigating the complex transition from pilot to commercial scale. For example, VC investors excel at evaluating early-stage technologies, while infrastructure funds offer deep experience in scaling, project delivery, construction oversight, and commissioning, related to Project Development, Integration, and Management (C.2), which is often beyond the scope of traditional VC. Growth equity and private equity investors evaluate managerial capability, workforce strength, supply chain robustness, and long-term unit economics, crucial to dealing with Manufacturing & Supply Chain (C.4). Moreover, a collaborative model can enhance decision-making processes. As investors share responsibilities, coordinated decision processes help reduce blind spots, increase the quality of investment decisions, and provide a more rigorous evaluation. Syndicates can also enhance market access by leveraging strategic relationships with industrial partners, potential customers, and policymakers, thereby accelerating deployment and regulatory approvals, supporting all License to Operate (D) challenge dimensions. Furthermore, a strong syndicate can provide signalling power, "anointing" the company that gathered a large and diverse group of supporting organizations as a prospective long-term winner (True North Institute, 2025; CREO, 2024).

One example of a successful syndicate is Form Energy (iron-air batteries), a company that successfully assembled a syndicate combining early-stage conviction (VCs such as Breakthrough Energy Ventures and Capricorn) with later-stage scaling capabilities (TPG's The Rise Fund, CPP Investments, GIC Private, and Temasek Holdings). This allowed them to raise over $1.2 billion to build a factory of a magnitude larger than the one from which they shipped their first commercial unit, and as the investor syndicate included "safe" institutional names (TPG, CPP), conservative utilities felt comfortable signing contracts with a startup (Form Energy).

Form Energy successfully assembled a syndicate that allowed them to raise over $1.2 billion to build a factory of a magnitude larger than the one from which they shipped their first commercial unit.

While clearly powerful, the collaborative blended finance model faces barriers, primarily due to coordination challenges and governance complications posed by a dispersed body of equity owners with diverse KPIs to track and conditions to follow. Successful execution requires implementing workable governance models that borrow from the VC world, typically involving a lead equity investor to coordinate activities and Investor Ecosystem in Blended Finance (True North Institute, 2025).

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[5] A syndicate in blended finance is a coordinated group of public and private investors that jointly finance a project, each taking on different layers of risk and return (True North Institute, 2025).

Investor Ecosystem in Blended Finance

Investor Type	Definition	Representative Examples	Primary Function	Limitations
Public Institutions	Government entities providing non-dilutive funds (grants, loans, tax benefits) and guarantees.	EU Innovation Fund, European Investment Bank (EIB), U.S. Department of Energy Loan Programs Office (DOE LPO), China's National Development and Reform Commission (NDRC).	Support legal due-diligence and design, connect to relevant policy programs, provide catalytic grants, guarantees, and concessional loans to derisk private investment.	Not designed for rapid deployment or high-return expectations; bureaucratic processes and long approval cycles.
Corporate Partners	Strategic inves-tors, mostly CVCs.	Microsoft, Shell, Mitsubishi Heavy Industries (MHI), NextEra, Amazon.	Provide operational expertise, technology validation, lowering CAPEX by access to their network and facilities, and guaranteeing demand through offtake agreements.	Not suitable as lead financiers; their investments depend on strategic alignment, not just financial yield. They rarely fund early R&D or assume un-proven technical risks. If the technology is competitive to them, they may choose to internalize it early without reaching full scale.
Private Investors	Non-governmental capital providers, such as venture capital funds, growth equity, private equity, institutional inves-tors, and banks.	Breakthrough Energy Ventures, TPG Rise Climate, Generate Capital.	Specialized expertise, including financial structuring, governance, commercial strategy, and operational oversight. Can catalyse later-stage financing, as strong private investor participation signals credibility to banks, corporate partners, and project-finance lenders.	Limited capacity for long-duration or asset-heavy projects; seek eventual exit or liquidity and may withdraw before project maturity. Investors willing to take a risk provide incomparably smaller checks than needed for a FOAK.
Impact-Oriented / Alternative Lenders/ Development Banks	Non-traditional financial platforms that provide concessional or non-dilutive capital (loans or grants) motivated by achieving project impact.	Temasek-backed lenders, Prime Impact Fund.	Non-dilutive capital, crowding in private capital	Institutions in this category often lack the relevant network and knowhow for technological scale up, and tend to prefer impact over profit. Their involvement is conditioned upon rigorous monitoring, reporting, and verification to justify concessional terms.

(Birshan et al., 2024; Black & Melendez, 2024; Freeman, 2024; Granskog et al., 2025; Przadka et al., 2025; True North Institute, 2025; U.S. DOE, 2024).

Human Capital

A recurring barrier identified in the Workforce (C.6) dimension is the difficulty of shifting from an R&D mindset to the risk-averse, safety-critical discipline required for plant operations. To mitigate this, startups planning and executing a FOAK need employees with experience in development projects (Cohen et al., 2024). They should recruit veterans from legacy industries (oil & gas or chemicals, for example) for construction and operational roles to import rigorous operational discipline.

When building a factory, practical on-the-ground experience is essential; therefore, hiring professionals with the required expertise is critical.

Startups often think they should hire smart people, not necessarily experienced ones, because they will figure out the new challenges they face. But what might be true in ideation and software development is by no means true for building a factory, where they actually need practical on-the-ground experience. In this stage, they need a team that has previously built factories in various locations and under different conditions, and that will know from experience how to solve problems and plan in a way that can actually be executed (Pratty, 2024). This is also critical to demonstrate to investors that the team can manage Engineering, Procurement, and Construction (EPC) workflows (Barclays, 2024; Pratty, 2024).

As Jack Haynes, Head of Investment at True North Institute, contrasts the typical startup mentality with what is needed for FOAK:

> *"Founders of businesses... are told to move fast and break things, and then they need to shift their mindset more to development expertise. Lots of them don't have those internal capabilities, so they need to hire people."*

It is especially crucial for the company's leadership, the board of directors, and the CFO, who must have project development experience. It is true not only for engineers but also for the finance team. When a company signs a large debt deal ($100M, for example), there will be someone in the financing organization whose role is to first analyse the deal and, once closed, to keep track of it. Therefore, it is useful to have someone on the company team with experience in investment banking or similar financial sector organizations who can support the relationship and provide relevant metrics while speaking the same language.

In addition to the personnel adaptation, the company structure must also evolve to a commercial framework with distinct departments and rigorous manufacturing protocols. Kobi Altman, CFO of Remilk, describes this shift from R&D to a commercial stage as a “dramatic event”. He mentions that they had to establish new commercial departments and move employees and resources from R&D to new departments. They had to lead internal restructuring and capital reallocation processes to implement industrial production protocols after most of the development was complete.

Techno-Economic Analysis and Third-Party Validation

While R&D lab results often ignore the 'boring' costs of pumps, pipes, and grid connections inherent in Infrastructure (C.3) and Implementation (A.3), a robust Techno-Economic Analysis (TEA) exposes these hidden liabilities early, validating whether the technology can truly achieve the Delivered Cost (A.1) parity required for market adoption. To validate a project's economic viability before steel is cut, companies must rely on robust Techno-Economic Analysis (TEA). A TEA is an evaluation tool that combines technical and economic aspects to assess the feasibility, competitiveness, and potential impact of a technology or project (Werny, 2025). Because every TEA is unique, founders should use multiple resources to construct a model that fits their specific process. Crucially, this is not merely a late-stage requirement but a valuable tool even at the earliest stages of company building.

Effective analysis requires a broad scope. Effective, broad-scope analysis, as emphasized by the DOE, requires defining technical parameters and estimating comprehensive capital and operating costs. Crucially, a robust TEA must employ system-level thinking, modelling all necessary components, not merely the core innovation.

The goal of an early-stage TEA is not to predict an exact price, which is impossible, but to identify "showstoppers." Founders should use Tornado Diagrams to analyse results under varying key parameters and conduct a sensitivity analysis, identifying the 2-3 variables (e.g., electricity cost or membrane yield) that have the power to make or break the company (Burk, 2022). Furthermore, models should account for "disaster risk" factors often ignored in optimistic scenarios, such as flawed utilities and volatile supply chains affected by geopolitical changes (Mohorčich, 2019). Then, founders should practice "Honest Benchmarking" by comparing their technology to the future costs of incumbents, not just their current prices, since some incumbent technologies are becoming cheaper and more efficient to produce (Burk, 2022). Finally, to convert these internal projections into bankable confidence, founders should engage independent engineering firms to conduct third-party validation, ensuring that the model's logic and assumptions withstand investor due diligence scrutiny (Freeman, 2024).

Founders should engage independent engineering firms to conduct third-party validation, ensuring that the model's logic and assumptions withstand investor due diligence scrutiny.

To conduct a TEA defensibly, founders can utilize:

- External Models: Resources such as the DoE's Life Cycle Assessment and Techno-Economic Analysis and the IEA's Global Energy and Climate Model provide cost projections and learning curves for over 800 technologies. This allows startups to forecast how their "Nth-of-a-Kind" CAPEX and OPEX will compete under different global policy scenarios (such as net zero vs. stated policies).
- Wright's Law: Models should account for the "high ceiling" of climate solutions. By Wright's Law, costs for manufactured technologies typically drop ~20% for every doubling of production capacity, whereas fossil fuels tend to get more expensive as easy deposits are exhausted. (Carbon Collective, 2026)

The "Villain Test"

To mitigate the Delivered Cost (A.1) risk where the "green premium" often proves to be a fragile and temporary subsidy, founders must subject their business models to a "Villain Test." This concept demands that a product be viable even for a hypothetical "villain" who cares nothing for the climate. To ensure long-term survival, the business model must be profitable on a standalone basis, relying on superior unit economics rather than government subsidies or the altruism of early adopters. As Yair Reem, Partner at Extantia, put it:

"This isn't about funding climate for climate's sake. The technologies we're bringing to market are fundamentally better, faster, and cheaper. They happen to be green. For the large industrials, this is a competitive advantage - not a compliance exercise."

This essential testing is required because of market dynamics: studies show that basic product features are much more influential in customer purchasing decisions than social and environmental advantages. This pattern is evident with B2C consumers and is even more pronounced in B2B procurement choices (Dalsace & Challagalla, 2024).

Companies entering a new market should either set a target price based on the incumbent price or analyze the added value their product provides, along with its sustainability impact, compared to the competition. To bridge this value gap, successful climate companies often employ a 'Trojan Horse' strategy, leading with performance rather than sustainability:

- Tesla captured the market by selling "speed and luxury," treating carbon reduction as a secondary benefit.
- Oatly, the Swedish alternative dairy company, drove adoption by marketing "anti-establishment cool" rather than sustainable agriculture.
- Soil carbon sequestration startups succeed by offering technologies that improve soil health and crop yields, thereby directly boosting farmers' bottom lines (Wan et al., 2022).
- Ultimately, climate technologies win market share when they transition from being an ethical choice to a purely superior economic and functional one.

While rapid scale-ups can help secure better commercial terms and capture the market, a gradual approach enables continuous adaptation and derisking throughout deployment.

Fast vs. Gradual Scale Up

The tension between the need for speed to secure market share and the need for caution to minimize risk is central to the Manufacturing & Supply Chain (C.4) challenge. It is not just about the flexibility of design, but also a broader strategic view that determines whether to build big facilities quickly or scale gradually. While rapid scale-ups can help secure better commercial terms and capture the market, a gradual approach enables continuous adaptation and derisking throughout deployment (Khatcherian, 2022).

Gradual scaling acts as a protective mechanism against "locking in" fatal economic flaws. It allows a company to realize that "using a certain material just isn't cost-effective at scale" and change it before the organization is committed to a billion-dollar asset (Yeh & CTVC, 2024). Yonatan Golan, CEO of Brevel, explicitly states that “the entire ecosystem

Source: Brevel

needs to undergo a change where investors and startups need to work slowly, and make sure they have a solid foundation before they continue to the next step. You cannot rush industrial scale-up."

Paradoxically, rapid scaling is often essential for a climate tech company to achieve bankability. Without large-scale production, companies face two major challenges: securing necessary inputs at competitive prices and supply certainty (which large producers benefit from), and locking in the massive committed offtake contracts (buyer agreements) often required, which a small pilot simply cannot sustain. Furthermore, accessing significant institutional capital ($100M+) is often predicated on "infrastructure-scale" opportunities, as many large investors cannot efficiently deploy smaller checks. Consequently, moving slowly can inadvertently heighten financing risk by keeping the company below the threshold for major institutional investment (McKinsey & Company, 2024).

A strategic middle ground may lie in the distinction between "scaling" and "stacking." Yair Reem argues that traditional FOAK scaling, expanding the physical dimensions and reactor capacity, is high-risk. In contrast, "stacking" involves replicating small, proven units to achieve volume. By building "5 liter [units] 10 times" rather than one 50-liter unit, companies can achieve commercial scale while significantly reducing the technical uncertainty associated with the scale-up of physical processes, mentioned in the Functional Performance (A.2) risk of inconsistent outputs.

A design change costing $1 in the digital phase can cost $10 during detailed engineering and balloon to over $100 during execution.

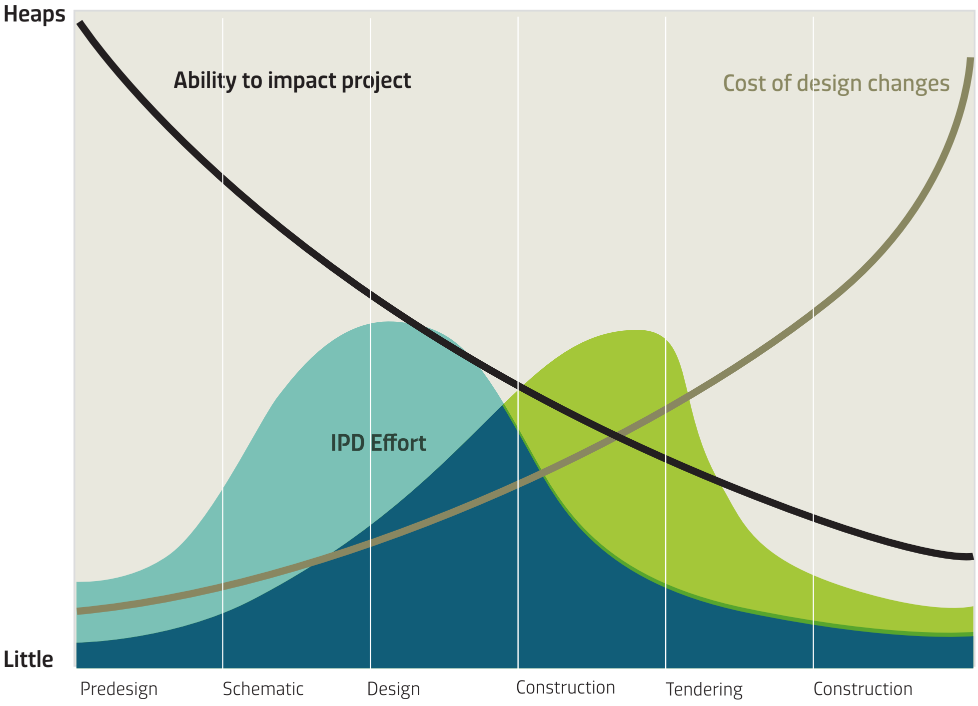
Flexibility vs. Sticking to the Plan

The Project Development (C.2) risk highlights that while startups adapt quickly to new needs and challenges, large infrastructure projects demand accurate long-term planning. In a complex infrastructure, the cost of modification follows an exponential curve. As significantly illustrated by the MacLeamy Curve and the "1:10:100 Rule," a design change costing $1 in the digital phase can cost $10 during detailed engineering and balloon to over $100 during execution. This escalation is due to the "Avalanche Effect," in which a minor tweak to a single parameter forces a costly redesign of deeply interconnected systems such as piping, structural supports, and electrical loads. Furthermore, without a locked specification, projects cannot secure regulatory permits or order "Long Lead Items" (such as custom reactors), effectively stalling the timeline (Eger et al., 2005).

While the golden rule of infrastructure is to make decisions early ("front-loading") to minimize costs, this creates a "Paradox of Front-Loading" for FOAK projects. By forcing early decisions to demonstrate maturity to investors, founders risk locking themselves into a design before they have finished learning. This creates a scenario where the team is efficiently executing a plan that may no longer be the best technical solution, trading optionality for efficiency (Davis, 2013). Guy Cohen, Senior Research Associate at Sightline Climate, notes that successful companies like Commonwealth Fusion Systems succeed partly because "they have a 10,000-point plan for how they get there," emphasizing extreme planning rigor.

Conversely, relying too heavily on "strategic fixedness" to satisfy investor timelines can be fatal. Rigid adherence to an unproven plan can lead to failure when technical challenges arise. Companies like Amyris survived precisely because they avoided technological inflexibility, pivoting to higher-margin markets when their original unit economics proved unviable

Source: Daniel Davis, https://www.danieldavis.com/macleamy/



MacLeamy Curve in Construction

(Mohorčich, 2019). Success lies in balancing the "10,000 point plan" with the structural agility to survive the unexpected.

A designer’s ability to influence the project is highest at the start, while the cost of making changes is lowest. As time progresses, these lines cross.

To resolve this paradox, successful companies adopt a strategy of "Front-loading flexibility". This means being ruthlessly experimental and open-minded when the stakes are low (R&D/Pilot), so they can be boringly consistent and rigid when the stakes are high (Construction/Commercialization). Once moving toward the "missing middle" (pilot to commercial), the mindset must shift. Infrastructure capital hates risk; therefore, the time for major pivots is over (Shales, 2024). The goal after the freeze is no longer "is this the best possible design?" but "is this the design we agreed to build?"

Tech companies should draw-out development stages and assign degrees of allowable flexibility to each - different design aspects should be categorized over time periods as free, internal freeze (made by an internal decision), an external freeze (regulatory or contracts’ restrictions), or a “chill” stage, where changes are discouraged but allowed if critical, in contrast to a freeze where changes are exponentially expensive. Companies shouldn't freeze the entire facility/product at once. "Front-load" the freeze for long-lead items (e.g., ordering the reactor steel) while keeping software or peripheral systems flexible for longer. This balances the need for speed with the need for agility (Eger et al., 2005).

Data Tracking and Insurance

A critical barrier identified in the finance dimension is the evolving insurability of novel technologies, mostly because FOAK projects lack historical performance data. As a result, insurers often cannot model

Companies must shift from viewing insurance as a procurement item at the end of the process to a strategic partnership developed during the pilot phase.

the risk, making it difficult to underwrite the project. Without insurance, projects struggle to get the needed regulatory permissions detailed in Permitting & Siting (D.3) and to unlock the debt capital necessary for construction as detailed in Capital Flow (C.1). To mitigate this, companies must shift from viewing insurance as a procurement item at the end of the process to a strategic partnership developed during the pilot phase.

The primary strategy to be considered is adopting an "Insurance Readiness Level" mindset. This essentially means translating the Technology Readiness Level (TRL) and the Adoption Readiness Level (ARL) to insurance terms and analyzing their "insurability" level. Startups should not wait for the construction phase to engage with insurers. Instead, dialogue should begin as early as TRL 6 (Demonstration/Pilot). Early engagement allows insurers and reinsurers to influence the physical design of the plant, such as the spacing of electrolyzers or the choice of safety materials, to ensure the final facility is "insurable" before blueprints are locked (The Geneva Association, 2023; Howden et al., 2024).

To support this dialogue, companies must rigorously track specific data points that insurers require to validate reliability over mere potential. While R&D teams often focus on peak efficiency, insurers require data that proves stability and predictability. These are some essential metrics to track from the pilot stage:

- Continuous Runtime Hours: Insurers look for "duration" (e.g., 5,000+ uninterrupted hours) to prove the technology has graduated from a science experiment to an industrial asset (Aon, 2024).
- Degradation Curves: Data showing how performance drops over time (e.g., membrane efficiency loss per 1,000 hours) is critical for insurers to underwrite performance warranties.
- Mean Time Between Failures (MTBF): Tracking the average time between system breakdowns helps quantify reliability.
- Root Cause Analysis: Every stoppage must be documented with a specific cause (e.g., "valve seal failure" vs. "software glitch") to prove to insurers that failures are isolated and fixable, rather than systemic design flaws.
- Performance vs. Ambient Conditions: Data on how the technology performs in extreme heat or cold is necessary to distinguish between technical failure and weather-related events, which is crucial for triggering parametric insurance payouts.
- By using this data and engaging early, companies could derisk various aspects through insurance.

Some examples of relevant insurance products include:

- Technology Performance Insurance (TPI) guarantees debt servicing if the new technology underperforms or fails to meet specific efficiency targets. It effectively "wraps" the technology risk, making the project bankable for lenders (Howden et al., 2024; New Energy Risk)
- Parametric Insurance is relevant for projects reliant on variable resources (e.g., wind or solar) or exposed to specific weather events. It can provide rapid payouts based on pre-defined triggers (e.g., wind speed or solar irradiance levels) rather than physical damage assessments (Hall & Walsh, 2025).

- Offtaker Credit Insurance provides coverage for cases where offtakers default. This insurance covers payment shortfalls, stabilising revenue streams for investors (Howden et al., 2024).
- Political Risk Insurance for projects in emerging markets. This protects against expropriation, currency inconvertibility, or political violence (London Market Group & Oxbow Partners, 2024).
- IP Insurance provides financial protection by covering litigation costs for defending patents, trademarks, and copyrights, as well as shielding against infringement claims (London Market Group & Oxbow Partners, 2024).

The case of Brightmark Energy serves as a prime example of how the strategies outlined above can successfully unlock capital for FOAK climate facilities. Brightmark Energy Plastics turns organic and plastic waste into sustainable products and fuel. It sought financing for its first commercial-scale plastics renewal plant in Ashley, Indiana. Despite successful pilot testing, the lack of a commercial operational history created a perception of high technology risk among investors, making it difficult to secure debt financing at favorable rates.

To overcome investor hesitation, Brightmark utilized a bespoke technology performance insurance policy that guaranteed debt service obligations would be met even if the new technology underperformed or failed to meet efficiency targets. In addition, the insurer (NER) worked closely with Brightmark's engineering team to conduct a comprehensive risk assessment using proprietary technoeconomic analysis. This rigorous modelling enabled the insurer to accurately price risk where traditional lenders lacked the technical expertise, thereby bridging the information gap for investors.

In climate tech, regulation is a fundamental market driver that dictates not only legality but also commercial viability.

Brightmark demonstrated agility by tweaking its project structure in response to insurer feedback during the pre-financing phase. As design and commercial parameters changed, the insurer provided guidance on optimizing the project structure to maintain financial viability and investor confidence. As a result, Brightmark successfully secured $185 million in green bonds (as part of a $260 million total raise) at a favorable long-term interest rate of 7.125% (New Energy Risk).

Policy-Led Strategy

As with insurance readiness, startups should be legal-ready, with this preparedness developed from the outset. The challenges in the Regulatory Environment (D.1) and the Policy Environment (D.2) highlight a critical strategic error: treating regulation as a fixed, purely technical external constraint that is addressed only after the technology is developed. In climate tech, regulation is a fundamental market driver that dictates not only legality but also commercial viability.

Soarce: Brightmark Energy

First, companies should integrate policy analysis into their earliest product and strategy decisions. Founders must decide early whether to design a product that fits into existing regulatory categories or one that requires rewriting the rules. Companies can scale faster by designing solutions that retrofit into existing supply chains or regulatory standards. For example, a "drop-in" fuel that meets current ASTM International fuel standards avoids the years-long struggle of certifying a new fuel category. From the MVP, companies should try to design the product so that it will be considered as a new version of a known technology to speed up regulation and approvals (University of Technology Sydney, 2024). Nevertheless, disruptive technologies often can't fall into any existing structure, and therefore must act as a "co-architect" of the transition, engaging with policymakers at the pilot stage to help draft the safety and environmental standards that will eventually govern and enable their market (See LanzaTech spotlight for more details).

Startups should map the potential markets and their legal environment. Because regulatory frameworks are fragmented globally, "policy readiness" should be a primary factor in selecting the first beachhead market (McKinsey, 2025). A product might be unviable in one region due to restrictive permitting but highly profitable in another due to specific incentives. Analyzing these differences early allows companies to align their "go-to-market" strategy with the path of least regulatory resistance, while accounting for policy and regulatory diffusion patterns, which can change the economic feasibility of a technology in the markets it aims to enter (Global Climate Finance Accelerator, 2025). EU regulation is stricter in many respects but might be a straw in the wind for further global regulatory restrictions, known as the “Brussels Effect” (Bradford, 2019). The design shouldn't necessarily meet the most stringent likely standard but should "future-proof" the technology for global export, preventing the need for costly re-engineering when expanding to new markets. Lastly, to achieve legal readiness, startups must hire or retain policy experts who can "translate" their technology into language that regulators and government financiers understand, and vice versa (Barclays, 2024).

> Because regulatory frameworks are fragmented globally, "policy readiness" should be a primary factor in selecting the first beachhead market.

Stakeholders: Governments and Ecosystem Players

Human Capital

While much attention is placed on the talent gaps within startups, a parallel knowledge gap exists on the other side of the table. For FOAK projects to succeed, the entities funding them, public institutions and private investors, must radically diversify their internal expertise. The current separation, where government bodies lack commercial agility and private investors lack industrial literacy, creates friction that stalls critical projects. To resolve this, both sides must cross-pollinate their teams with expertise from the respective domains.

For policymakers and public finance institutions, the priority is to integrate venture capital and tech equity expertise. Traditional infrastructure finance professionals, while skilled in compliance, often struggle to assess early-stage technology risk, which can lead to paralysis. By hiring professionals with VC backgrounds, public bodies can better assess technical upside, streamline application processes to match commercial pacing, and design flexible financial instruments-such as forgivable loans - that accommodate the ambiguity of FOAK projects (Barclays, 2024).

At the same time, private investors targeting FOAK assets must import industrial rigor by hiring team members or partners with deep infrastructure experience. Financial modeling alone cannot validate a chemical plant's engineering or supply chain strategy. Investors need in-house veterans from sectors like oil & gas, mining, or chemicals to perform technical due diligence, validate construction timelines, and sit on boards to provide guidance on operational aspects such as safety and permitting, ensuring that capital is deployed into viable, "hard-hat" ready projects.

As with startups, policymakers and innovation authorities should bring venture capital and tech equity expertise into public finance institutions, rather than relying solely on traditional infrastructure finance professionals who may not understand early-stage tech risk, while investors should hire consultants who have led large infrastructure projects.

Governments and ecosystem players should establish open-access databases that aggregate FOAK data into accessible platforms.

Establishing Open-Access Benchmarks

A recurring barrier for investors is the lack of transparent data on project costs and performance, which makes risk modeling nearly impossible. To bridge this gap, governments and ecosystem players should establish open-access databases for FOAK project costs and performance (Oliver & Rittblat, 2023).

As Alexa Thompson, Associate Director at Australian Renewable Energy Agency (ARENA), notes, while individual project reports often bury insights, aggregating this data into accessible platforms (like the ARENA Knowledge Bank) allows the broader market to learn from both successes and failures:

> *"The US has limited public knowledge sharing on project-by-project transparency of data detail. But I think the DOE sees a much broader role for market intelligence reports... ARENA does... more data collection on individual projects and assets and makes more of that available to the public through the ARENA Knowledge Bank."*

#1 investor request: case studies of successful deployments.

The urgency of this recommendation is reflected in our primary research. When asked what would most increase their confidence in FOAK investments, case studies of successful deployments were the most commonly cited factor among investor respondents, ranking above third-party technical validation and improved performance data.

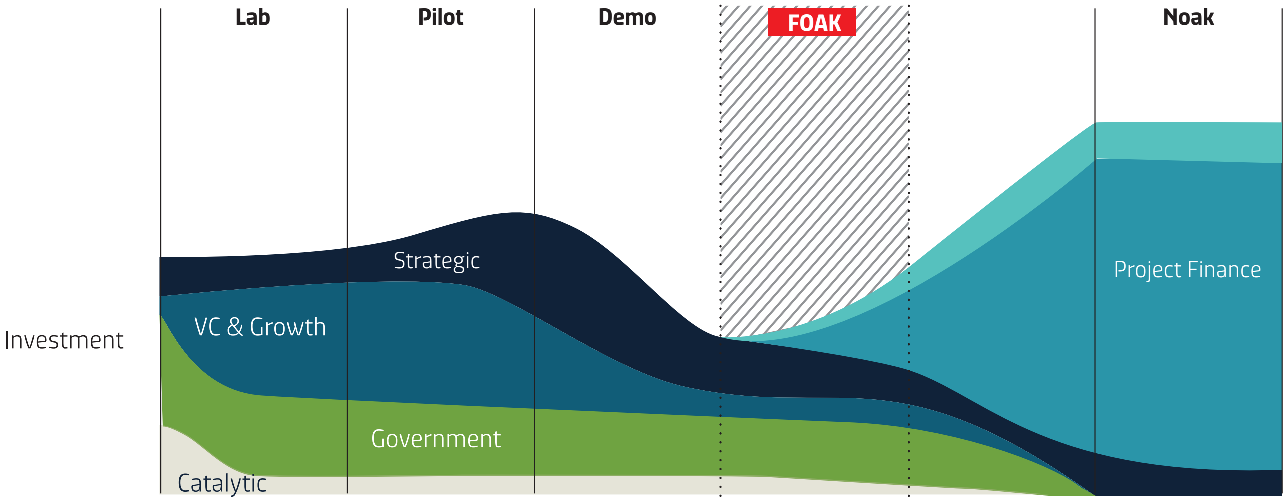
Establishing public benchmarks on capital costs, operational efficiencies, and "green premiums" provides the "institutional quality" data that financiers need to underwrite risk. This transparency helps standardize what is currently a fragmented and obscure market, reducing the diligence burden for every new deal.

Governments as Customers

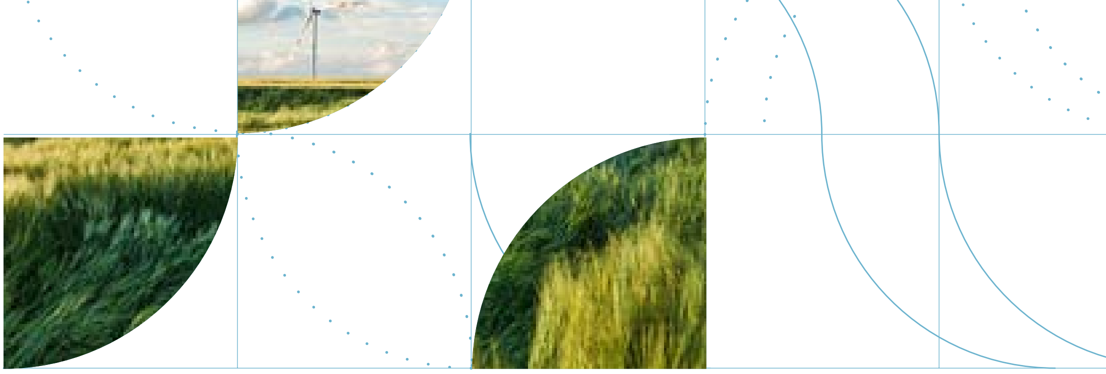
Beyond funding supply, governments must actively create demand. By using public procurement to act as a "lead market," governments can become the first buyer for green technologies, providing the revenue security startups need to survive the "Valley of Death". Governments can drive this transition through two primary mechanisms:

- **Public Procurement as a Trigger:** Rather than merely subsidizing construction (capex), governments should commit to purchasing the output (e.g., green hydrogen, low-carbon steel) at a premium for first batches, or at better conditions. By offering long-term offtake agreements or guaranteed price floors, the public sector creates a stable revenue stream that private markets cannot yet provide. For example, the US Federal Buy Clean Initiative, promoted by the previous US administration, prioritized the use of low-carbon construction materials in federally funded infrastructure projects to drive market demand for cleaner manufacturing. As part of this initiative, Ameresco's installation at the Denver Federal Center (DFC) was funded to eliminate 50% of the site's fossil fuel consumption in 2025 (Office of the Federal Chief Sustainability Officer, 2025). This "demand pull" validates the technology's commercial viability and gives private investors confidence that there is a guaranteed customer at the end of the production line.

- **Derisking through Offtake:** Secure buyer contracts (offtakes) are often the hardest piece of the puzzle for FOAK projects. Government-backed offtake agreements act as a gold standard, instantly lowering the risk profile for debt financiers who rely on predictable cash flows to approve loans.



The Road to FOAK



Closing Remarks

> What the FOAK stage ultimately demands is not perfection, but preparation: the foresight to anticipate structural challenges before they become crises, and the humility to seek the partners, frameworks, and knowledge that no single organization can develop alone.

The Road to FOAK set out with a question focused on the availability of capital – and arrived at something far more consequential. What began as an inquiry into financing gaps revealed a systemic mismatch between how climate technologies are built and the demands of commercial-scale deployment. The challenge is not simply that money is scarce. It is that the entire pathway from demonstration to FOAK facility is poorly suited to the realities of industrial-scale development: regulatory complexity, capital markets' risk aversion, organizational strain from scaling, and the long, unforgiving timeline between technical proof and a profitable plant. To arrive at the FOAK stage as prepared as possible, companies must assess their roadmap not only through a technological lens but also across financial, commercial, operational, and regulatory dimensions – all of which can prove decisive in determining whether a company scales or shuts down. The ARL framework and challenge mapping presented in this report are designed to support that process, helping companies develop a tailored strategy that reflects their specific needs and barriers.

The case studies of LanzaTech and UBQ Materials illustrate both the promise and the difficulty of this journey. These are companies with proven technologies, dedicated leadership, and real-world impact – and yet both navigated years of uncertainty, near-failures, and structural barriers that had little to do with the science. Their stories are instructive precisely because they are not outliers. They represent a generation of climate innovators who are capable of delivering solutions at scale, provided the ecosystem around them evolves to match their ambition. In addition, China's climate-tech spotlight offers further insight: the decisive advantage that coordinated national-level industrial policy, long-horizon capital, and deep supply chain integration can confer. It is not necessarily a model to be replicated wholesale, but it is a benchmark against which the West must measure the seriousness of its own commitments.

The Climate FOAK Playbook distils the most actionable insights from this research, such as front-loading flexibility into engineering decisions and building partnership ecosystems before they are urgently needed. These are not abstract principles. They are core elements of the operational logic of the companies and projects that have successfully crossed the Valley of Death.

This report is a starting point, not a conclusion. The FOAK landscape is evolving rapidly, and significant knowledge gaps remain. Future research should deepen sector-specific analysis as the barriers facing green hydrogen developers differ meaningfully from those encountered in carbon capture or innovative recycling technologies, requiring sector-tailored strategic guidance rather than generic frameworks. Such research should also rigorously evaluate which financing instruments, policy mechanisms, and strategies are producing measurable results in each sub-sector. Longitudinal studies tracking FOAK projects through construction, commissioning, and early operations can offer insights that no pre-commercial analysis can provide, including analysis of companies that successfully completed their FOAK but subsequently stalled, restructured, or failed. The strategic decisions made during the FOAK stage, around financing architecture, scale-up pace, team composition, and market positioning, carry consequences that only fully materialize in the years that follow, and Northvolt's trajectory illustrates the fault lines that current pre-commercial research cannot reach. The community of practice around FOAK deployment is still nascent. Building a shared knowledge infrastructure would accelerate progress across the entire field. Collaborative research initiatives that bring together practitioners and researchers around specific FOAK bottlenecks represent one of the highest-leverage opportunities available. Finally, the geopolitical transformation now underway is reshaping the fundamental economics and geography of climate technologies FOAK deployment in ways this report has only begun to trace. Oil price volatility, the accelerating fragmentation of global trade, and the emergence of competing industrial policy regimes across the U.S., EU, and China are not merely background conditions; they are actively determining where FOAK facilities can be viably sited, how large they should be, and which markets they can credibly serve. Research that systematically maps the intersection of these macro forces with FOAK decision-making would fill one of the field's most urgent gaps.

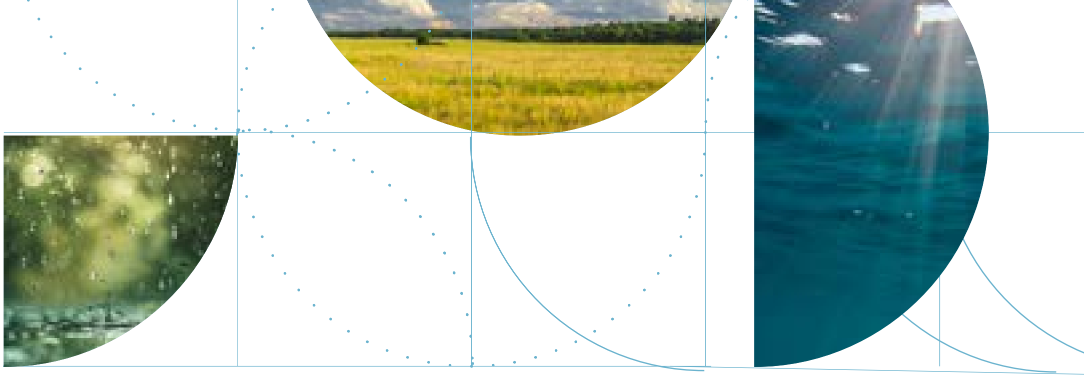
The challenge is not simply that money is scarce. It is that the entire pathway from demonstration to FOAK facility is poorly suited to the realities of industrial-scale development.

For entrepreneurs, the data is clear – successfully crossing the multiple stages of early development, from lab to pilot to demonstration, does not guarantee survival at the FOAK stage (Net Zero Insights, 2025). The FOAK is the most consequential and perilous transition in a climate technology company's lifecycle, and it demands a different kind of readiness. The imperative is to begin building the financial, commercial, physical, and relational infrastructure long before it is urgently needed. For investors, the complexity of these transactions rewards collaborative capital. Lack of experience in project development on the one hand or in deep-tech commercialization on the other is not, in itself, a disqualifier, as the investors best positioned to succeed in this space are those who build the right partnerships. For policymakers, the case for supporting the FOAK ecosystem extends well beyond industrial competitiveness. It is, more fundamentally, a prerequisite for achieving sustainable and economically efficient long-term energy resilience. A policy environment that enables climate technologies to reach commercial scale does not merely create stronger companies; it accelerates the deployment of solutions the world cannot afford to delay.

The climate transition will not be delivered by technologies that remain forever at the demonstration stage, and the consequences of a successful FOAK can affect both this generation of climate technologies and the next. They attract future entrepreneurs, validate the investment thesis for the next wave of capital, and prove to the market that deep-tech climate solutions can be viable businesses. The enormous effort invested in building early-stage companies will fail to generate lasting impact if those companies cannot achieve profitability at commercial scale, and if the technologies they develop cannot find a significant market on the other side of the Valley of Death.

Lastly, this report would not have been possible without the generosity of the international climate technology ecosystem. In the course of our research, we reached out to founders, investors, policymakers, and project developers spanning from Australia to the West Coast of the United States, and without exception, we were met with generosity both of time and hard-won knowledge. What struck us as much as the insights themselves was the spirit in which they were offered. Climate tech is a uniquely collaborative ecosystem, one where the motivation driving its participants extends well beyond their own success. The understanding that this sector rises or falls together is not merely an aspiration – it is simply how people show up. This is something worth knowing for founders entering this space and for new stakeholders finding their footing in it. We are deeply grateful to everyone who gave their time and knowledge to this research, and in publishing this report, we hope to reflect the same spirit they showed us.

The road to FOAK is difficult - but it is not impassable. The barriers are real, the timelines are long, and the margin for error is narrow. But the technologies exist, the entrepreneurs are building, and the ecosystem, as this report shows, is more willing to help than many first assume. What the FOAK stage ultimately demands is not perfection, but preparation: the foresight to anticipate structural challenges before they become crises, and the humility to seek the partners, frameworks, and knowledge that no single organization can develop alone. The companies that have crossed the Valley of Death did not do so because the conditions were favorable. They did so because they understood the terrain. That understanding is what this report set out to offer, and if it helps even a handful of the next generation of climate technologies reach the scale the world needs, the work will have been worthwhile.



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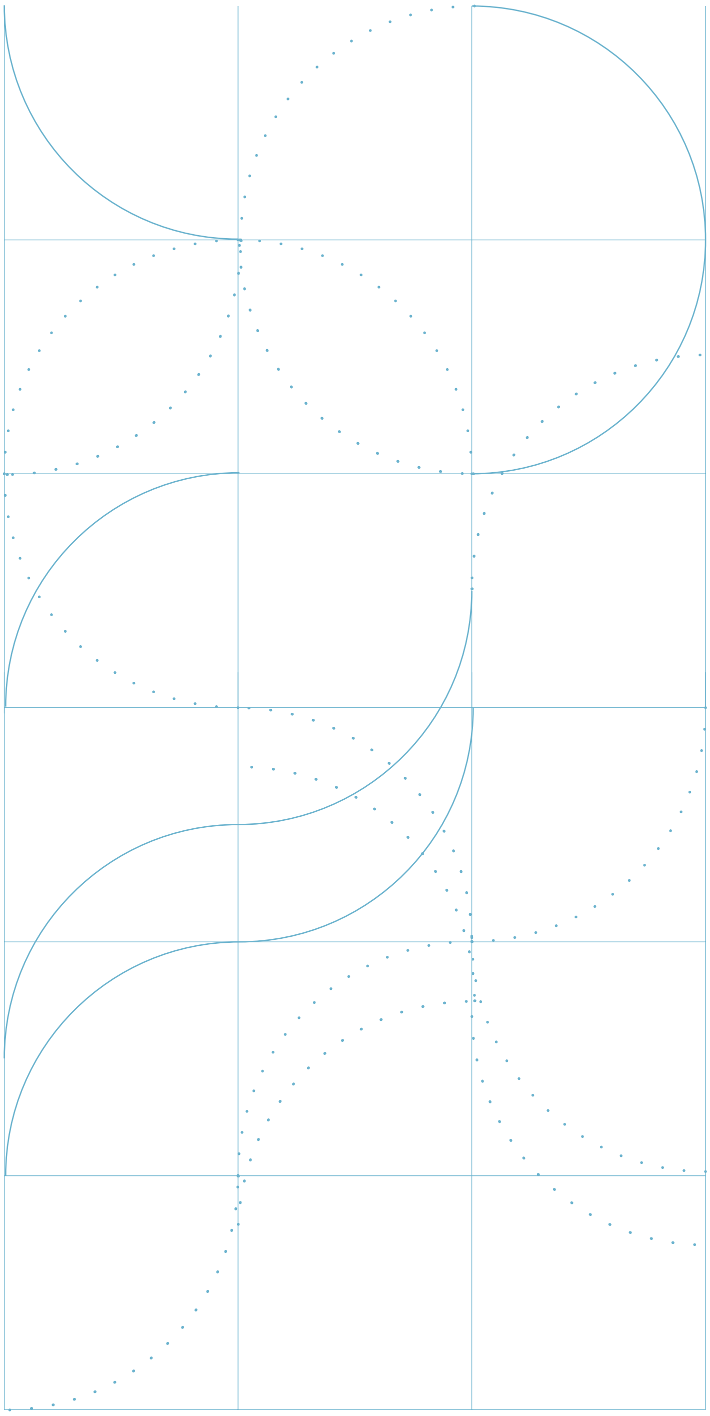

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