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Workforce readiness: the missing lever for scaling climate technologies

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Scaling climate technologies requires not only capital and innovation but people. Workforce readiness has emerged as a critical yet underdeveloped determinant of whether early-stage climate technologies successfully reach commercial deployment. This opinion is informed by extensive engagement with entrepreneurs, operators, investors, and policymakers across nuclear, geothermal, biomanufacturing, carbon management, and energy storage. We highlight cross-cutting gaps in early-stage policy fluency, interdisciplinary agility, skilled trades, plant operations, and commercial leadership—all of which shape the pace and success of deployment. We argue that education and workforce systems at all levels remain mismatched to real commercialization needs. We propose targeted strategies for community colleges, universities, and executive training programs to align skills with emerging industry demand. Strengthening workforce pipelines is one of the most powerful and underused levers to accelerate climate technology scale-up.

Broader context

The global energy transition is now entering a critical phase: deployment of innovative climate technologies must accelerate at unprecedented scale while labor markets, educational systems, and workforce pipelines struggle to keep pace. Conventional engineering, finance, and policy levers are necessary but not sufficient—human capital remains a major, under-leveraged constraint on commercialization. In this Opinion, we draw on 34 expert interviews across nuclear, geothermal, biomanufacturing, carbonmanagement and energy storage sectors to highlight how workforce readiness constitutes a proximal rate-limiting factor for climate-tech scale-up. By reframing workforce development as a core commercialization accelerator rather than a peripheral topic, we offer actionable pathways for aligning education, training and industry to meet net-zero deployment imperatives.

1. Introduction

Climate technology deployment is accelerating globally, but workforce readiness has not kept pace with national and international goals for emissions reductions. Foundational labor analyses forecast significant job creation driven by climate mitigation, adaptation, and energy system transformation, with the World Economic Forum projecting climate-related fields as major contributors to global net job growth by 2030.[1] Yet even as employment expands, the supply of workers with ''green skills'' lags behind, and experts warn that ''whether the energy transition happens fast or slow, what is clear is that the global workforce is not ready for the changes to come.''[1,2] The rapid scaling of AI and the accompanying demand for data centers is further intensifying the need for workers capable of bridging digital and physical energy systems.[3]

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While workforce challenges in climate technology are global, many of the institutional dynamics discussed here reflect the United States innovation ecosystem, where venture-backed climate technology firms are increasingly attempting to scale first-of-a-kind infrastructure projects.

Human-capital readiness now represents a structural fault line in the energy transition. The International Energy Agency estimates that roughly 35% of emissions reductions required for net-zero by 2050 depend on technologies not yet demonstrated at commercial scale—technologies that cannot advance without a workforce able to ''design, produce, install, maintain, and operate at scale.''[4,5] Workforce shortages are increasingly documented across international analyses, including IRENA's and ILO's Renewable Energy and Jobs reviews, OECD assessments of local workforce capacity, and sector-focused industry studies.[6–9] Without credible pathways for worker reskilling and economic security, climate policies can trigger political resistance linked to workforce displacement and regional economic disruption. These dynamics have been widely discussed in the "just transition" literature, which highlights how poorly managed labor transitions can undermine public support for climate policy and delay energy system transformation.[10–12]

This opinion addresses two core questions: (1) what specific workforce bottlenecks most constrain the commercialization of emerging climate technologies? and (2) how should education and training systems evolve to better prepare workers for early-stage and commercial-scale deployment?

Informed by extensive engagement with climate technology entrepreneurs, operators, investors, and policymakers, we synthesize workforce challenges across sectors and development stages. We argue that educational institutions—from community colleges, universities, to executive programs—are uniquely positioned to accelerate climate technology scale-up, but only if curricula more directly align with commercialization realities.

We focus on advanced nuclear, next-generation geothermal, electrochemical energy storage, and carbon management because they span distinct physical systems, regulatory regimes, and commercialization pathways. Together these sectors represent technologies at different points along the deployment lifecycle—from early prototype systems to infrastructure-scale deployment—allowing workforce bottlenecks to be compared across stages of commercialization.

The arguments presented here reflect the authors' synthesis of recurring themes emerging from extensive engagement with climate-technology practitioners between 2024–2025.

2. Workforce bottlenecks across the commercialization lifecycle

2.1. Early-stage talent needs

Early joiners, *i.e.*, the first non-founder hires, play an outsized role in whether a startup can successfully commercialize by embedding organizational capital that forms the foundation of a company's scale-up.[13] For early-stage clean energy startups at the lab and prototype stages, two early hire skillsets repeatedly emerged as particularly important for preparing teams for scale-up: (A) policy fluency and (B) agility in both technical and non-technical roles. Many teams hired policy and community engagement leaders early to navigate permitting, regulatory approvals, community partnerships, and local talent pipelines, enabling on-time project execution. When these capabilities are absent, permitting delays and design rework frequently extend project timelines, increasing lifecycle emissions intensity and slowing early technology learning rates. For nuclear in particular, regulatory and policy expertise remains a persistent workforce challenge. Early efforts to address workforce gaps are also emerging across other sectors.[3] Early efforts to build local workforce pipelines are already emerging in some sectors. For example, geothermal developer Fervo Energy has partnered with Southern Utah University to develop apprenticeship programs that retrain oil and gas workers and local students for geothermal project development and operations. Fig. 1 provides an illustrative synthesis of where workforce pressure points tend to emerge across technologies and commercialization stages and serves as an organizing framework

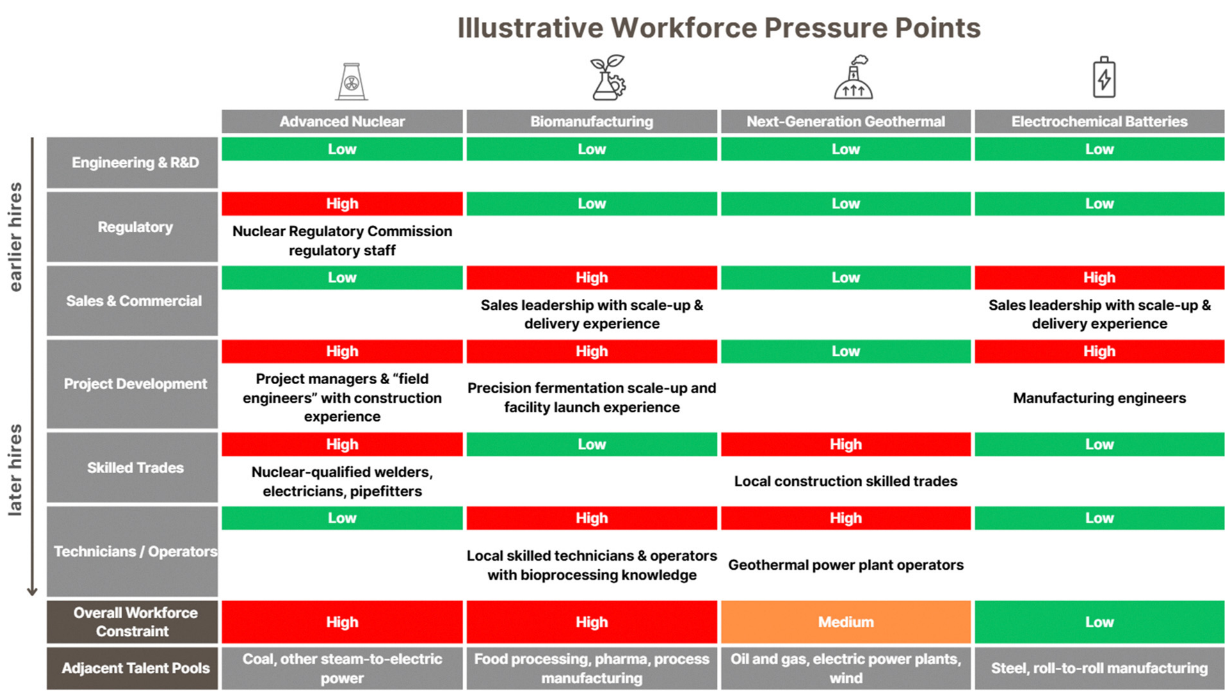

Fig. 1 Illustrative workforce pressure points across climate technology sectors. Directional patterns repeatedly raised in expert conversations, presented to illustrate where workforce constraints tend to emerge across the commercialization lifecycle—from early venture formation and prototype development through infrastructure construction and operational deployment—across advanced nuclear, biomanufacturing, next-generation geothermal, and electrochemical batteries.

for the discussion below. Fig. 1 therefore serves as a conceptual framework linking the workforce challenges discussed in Sections 2.1–2.3.

Early-stage climate technology ventures frequently require ''specialist generalists''—individuals with deep technical expertise who can operate flexibly across engineering, operations, and policy domains. Early employees in climate technology ventures often require rapid cross-training in both technical and operational skills. For early non-technical roles, founders similarly sought interdisciplinary thinking and entrepreneurial mindsets that would enable employees to thrive if needs shifted after hiring, as well as the ability to develop technical fluency to understand and externally communicate product offerings. The ability to ''blend technical expertise with human-centered capabilities'' is seen as increasingly important with the pace of technological development.[1]

Educators in science and engineering can better equip graduates for roles in climate technology by embedding interdisciplinary project-based learning into curricula, emphasizing real-world applications of technical knowledge, and integrating policy literacy early. Courses or extracurricular experiences that teach students to engage directly with communities, policymakers, and stakeholders can develop the skills needed to navigate permitting and regulatory environments. Additionally, building modular training programs that pair deep technical education with practical entrepreneurial experiences, such as internships with early-stage ventures, will prepare graduates to quickly adapt to evolving roles within dynamic startup environments.

2.2. Commercialization-stage workforce gaps

As climate technologies move from laboratory development toward infrastructure construction and operations, workforce needs shift significantly. Early-stage ventures require flexible interdisciplinary talent, whereas commercialization demands specialized capabilities in project development, construction, operations, and market formation. Across sectors, four workforce bottlenecks repeatedly emerge during this transition: (A) senior project development managers, (B) skilled tradespeople in project development, (C) skilled technicians in project operations, and (D) senior commercial talent.

2.3. Cross-cutting workforce themes

Like the early hiring focus on agility and interdisciplinary skills, commercial-ready teams looked for entrepreneurial and ''practical'' mindsets during project development. Whether they outsourced engineering, procurement, and construction (EPC) or hired in-house, operators advocated for maintaining tight control over early projects and sought project development managers with sector-specific technical fluency, attention to detail, and adaptability. Mid-career and executive education programs can address talent bottlenecks by offering specialized training in climate-focused project management and interdisciplinary collaboration. Curricula should include rapid prototyping, agile management techniques, risk assessment, regulatory strategy, and stakeholder engagement specific to energy infrastructure projects. Short, intensive executive courses or certifications on emerging climate technologies, blended with case studies from successful commercialization efforts, would help mid-career professionals pivot into climate-focused roles and drive effective project execution and commercialization. In capital-intensive energy infrastructure, gaps in project development expertise can delay commissioning and financing milestones, prolonging reliance on higher-emissions incumbent systems.

Skilled trades workers were another frequently cited workforce bottleneck during project development, consistent with broader research documenting persistent shortages in U.S. skilled trades.[14] For large-scale new plant nuclear construction, the most in-demand skills are specialized craftworkers (*i.e.* welders, pipefitters, electricians) with nuclear-specific certifications and training such as radiation health physics.[15] Nuclear developers highlighted valuable ''field engineers'' who can engineer and design but also understand the real physical environment and troubleshoot in the field. For electrochemical batteries, the gap is in manufacturing engineers with hands-on expertise and trade secrets in setting up large-scale battery manufacturing equipment and processes—a skillset companies are bringing in from South Korea today. Community colleges, technical schools, and union training centers are pivotal in addressing gaps in skilled trades for climate projects. These institutions can develop targeted training programs in specialized trades, such as welding, electrical work, and field engineering, tailored specifically for clean energy sectors, including nuclear, geothermal, battery manufacturing, and carbon management. To ensure graduates are immediately employable, educators should co-develop curricula with business leaders, integrate practical, hands-on apprenticeships or internships, and offer certification programs recognized by industry and regulatory bodies. Shortages of certified craft labor can introduce construction delays, rework, and safety risks, increasing project costs while slowing the effective pace of clean energy deployment.

When companies transitioned from construction to operations, they frequently encountered local shortages of skilled technicians, site engineers, supervisors, and plant operators, particularly in rural or resource-constrained regions lacking established talent pipelines. To overcome these challenges, companies reported partnering with labor unions to deliver certified, high-quality workforce training; launching apprenticeship programs that integrate classroom instruction with hands-on experience; investing in professional development and reskilling initiatives to improve retention and adapt legacy workforce mindsets; and collaborating with community and technical colleges to co-develop industry-aligned curricula. For example, Fervo Energy created a geothermal apprenticeship with Southern Utah University and Elemental Impact to retrain oil and gas workers and local college students for roles at its Cape Station project,[16] while Liberation Bioindustries partnered with Ivy Tech in Indiana to design tailored biomanufacturing training programs.[17] Companies also emphasized the importance of engaging students at early education levels to build awareness and interest in emerging industries: Fervo, for instance, introduced geothermal concepts to third and fourth graders,[18] and MycoWorks is educating South Carolina high school students about mycelium.[19] Once operational, insufficiently trained operators can reduce capacity factors and system reliability, eroding the emissions benefits and economic performance of deployed assets.

Educators at community and technical colleges can further strengthen local talent pipelines by proactively identifying critical skillsets sought by regional employers and co-designing modular, hands-on training programs to meet these needs. However, these programs should balance specificity with broader industry transferability, as overly customized credentials may limit graduates' mobility unless associated with recognized, legacy employers. Additionally, educators can facilitate mid-career transitions into clean energy roles by redesigning traditional two-year degree programs to serve as flexible bridge programs that combine targeted technical training with practical exposure to startup environments.

Across nearly all climate sectors and company sizes, commercial and sales leadership emerged as the most frequently cited workforce bottleneck. Teams highlighted a critical shortage of talent experienced in scaling sales within emerging markets, particularly those with experience structuring, negotiating, and delivering offtake contracts and commercial agreements beyond preliminary joint development agreements, memoranda of understanding, or licensing deals. Climate technology companies often require commercial leaders capable of creating markets for entirely new products. Ideal candidates were those who had successfully launched entirely new value chains, such as early-stage liquified natural gas markets, and could structure complex commercial agreements, secure initial customer commitments, manage risks inherent to immature markets, navigate evolving global legislation and incentives, and effectively engage local regulators and community stakeholders to move projects from concept to deployment.

Many companies strategically recruited leaders from incumbent industries targeted for disruption, leveraging their procurement expertise and ability to translate novel technologies into language and frameworks familiar to established buyers. Additionally, organizations sought commercial executives possessing sufficient technical fluency and entrepreneurial agility to contribute directly to product leadership, adeptly interpreting customer feedback and guiding product development in parallel with market-building activities. To effectively prepare students for commercial roles in climate technology, business schools should integrate cross-departmental coursework fostering technical fluency along with specialized training in sales strategy, new market development, offtake contracting, deal structuring, policy navigation, and stakeholder management.

Across technologies, these commercialization-stage workforce gaps shape not only project timelines and costs, but also the realized environmental performance of energy systems.

3. Educational strategies to strengthen workforce pipelines

3.1. Recommendations for educators: bridging the workforce gap

The workforce bottlenecks identified above imply different educational responses across the talent pipeline. Preparing workers for climate technology commercialization therefore requires coordinated action across multiple educational levels—from early exposure to climate technologies in K-12 education to specialized technical training in community colleges, interdisciplinary programs at research universities, and targeted executive education for mid-career professionals. A common theme emerging from industry feedback is the importance of embedding interdisciplinary skills, practical experiences, and industry-specific training at all educational stages. Recommendations for workforce training programs are summarized in Fig. 2, focusing on post-secondary and professional education pathways most directly aligned with climate technology deployment.

For community and technical colleges, educators can improve traditional associate degree programs by proactively engaging industry partners to identify workforce needs and co-designing curricula that combine practical hands-on skills with industry-recognized qualifications. However, because the future of many new technologies and policy support for them is uncertain, effective education and training programs should balance specialization with transferable, future-proof skills, preparing graduates for immediate employment while enabling long-term career "flexibility and adaptability" in case a company pivots or a technology does not reach commercialization at scale.[20,21] Upskilling and reskilling initiatives should "prioritize flexibility to reduce barriers to participation."[6] Community and technical colleges should develop new, shorter, and more accessible bridge programs to support mid-career or skilled professionals transitioning from adjacent sectors into climate tech. These modular training courses can provide targeted technical training paired with practical exposure to dynamic startup workflows, overcoming barriers posed by traditional two-year degree structures.

At research universities, particularly within science, engineering, and policy programs, interdisciplinary, project-based curricula should become central. Existing academic programs across these domains can be modified to blend rigorous technical education with practical, entrepreneurial, and policy-oriented training, better equipping students for the multifaceted challenges they will face during the commercialization of new technologies. Universities should facilitate direct student engagement with policymakers, regulators, and local communities through internships, experiential courses, and real-world practicum opportunities. Educators are encouraged to embed modules on regulatory strategy and community stakeholder management within existing coursework, preparing graduates to navigate complex commercialization environments.

Executive and mid-career education programs can significantly impact climate tech sectors by designing specialized

	Educator Action Recommendations
Community & Technical Colleges	• Partner with industry to co-design curricula combining hands-on skills with industry-recognized and portable certifications. • Develop modular bridge programs to support mid-career transitions from adjacent sectors and overcome barriers posed by traditional two-year degrees.
Research Universities	• Implement interdisciplinary, project-based curricula blending technical education with practical, entrepreneurial, and policy-oriented training. • Facilitate direct student engagement with policymakers, regulators, and communities through internships and coursework.
Executive & Midcareer Education Programs	• Design executive and mid-career programs focused on climate-specific project management, agile leadership, and interdisciplinary collaboration. • Include case studies and simulations covering commercialization, contract negotiation, risk assessment, and stakeholder management.
Business Schools	• Integrate interdisciplinary coursework that enables technical fluency development. • Include commercial training in market creation and contract structuring, as well as case studies on policy navigation and stakeholder engagement.

Fig. 2 Summary of recommended actions for education institutions. Summary of key recommendations of actions for educational institutions to prepare students to scale climate technologies.

training focused on climate-specific project management, agile leadership methodologies, and interdisciplinary collaboration. These programs should include detailed case studies of successful technology-to-market transitions, practical simulations in contract negotiations, risk assessments, and stakeholder management strategies tailored explicitly to the unique demands of the clean energy and climate industries.

Lastly, business schools can enhance their curricula by integrating interdisciplinary programs that develop technical fluency alongside specialized commercial training. Courses should specifically address market creation, negotiation and structuring of commercial contracts, policy navigation, and stakeholder engagement. By equipping future commercial leaders with comprehensive technical and entrepreneurial skills, business schools can substantially contribute to addressing the critical shortage of skilled sales leadership identified across climate tech sectors.

Together, these educational strategies, implemented consistently across educational institutions, can meaningfully address workforce gaps, facilitate smoother pathways to commercialization, and accelerate the transition toward robust and innovative climate technology ecosystems (Fig. 2).

4. Outlook and call to action

Scaling climate technologies requires not only technical innovation and capital formation but a workforce capable of deploying and operating systems in the real world. Workforce readiness now determines the pace at which first-of-a-kind (FOAK) projects can cross the valley of death, meet net-zero deployment timelines, and respond to rapidly rising energy and data-center demand. While a reactor, electrolyzer, geothermal plant, or biomanufacturing facility can be designed in months, building the workforce to operate these systems can take years. At this critical juncture, aligning education and workforce pipelines with the actual needs of commercial deployment is among the most impactful yet underused levers available. A coordinated strategy linking educators, industry, unions, philanthropy, and policymakers can accelerate technology learning rates, strengthen regional economic resilience, and meaningfully improve the probability that climate technologies scale at the speed required to meet global climate goals.

Conflicts of interest

The authors declare no competing interests related to the content presented in this opinion.

Data availability

No new primary data were created for this opinion article.

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