From IMPEL to Impact: Lessons Learned in Accelerating Innovative Building Technologies

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ABSTRACT

The built environment is a complex ecosystem of social institutions and physical infrastructures. Innovation and entrepreneurship in the building industry are critical levers for market transformation toward equitable climate action. However, climate tech innovation for the built environment is not moving fast enough for global needs, and it lacks fundamental diversity, leading to inequitable outcomes. IMPEL (Incubating Market-propelled Entrepreneurial-mindset at the Labs and Beyond) - a U.S. Department of Energy incubator–addresses these critical issues. Over five years, IMPEL has enabled 250 innovators, including 55% women and diverse founders, to accelerate their buildings and clean energy technologies towards market and climate impact. IMPEL provides access to strategic mentoring and coaching, carbon tools training, testbeds, and powerful public-private pipelines, including industry demonstrations, non-dilutive grants, and venture capital networks. The IMPEL innovation ecosystem has accelerated the pace of innovation and market adoption of building decarbonization technologies. In this paper, leverage the IMPEL stakeholder ecosystem - from innovators to investors and product industry to policymakers - to analyze the critical barriers to decarbonization still encountered in the building industry. We study the IMPEL approach and highlight lessons learned that benefit young businesses pursuing innovative building and building-edge energy technologies to develop new ideas and products. Finally, we propose a 'market forming' framework to improve the quality and efficiency of the entrepreneurial ecosystem in the building industry. This framework could scale vetted technologies and the participation of diverse founders to de-risk the climate tech industry and create economic growth towards an equitable zero-carbon built environment.

Introduction

Background

The built environment has a profound physical, emotional, and economic impact on our lives. It comprises our families' homes, the buildings we work and shop in, the schools our children learn and play in, and the spaces our communities can thrive in. While underscoring our relationship with the natural environment around us, buildings are a primary global industry, responsible for a 36% share of global energy consumption in 2021 (Global ABC Report 2022) and a significant economic footprint valued at USD 10.9 trillion in 2020 (Statista 2023). The built environment contributes a substantial share of global energy consumption and emissions, accounting for approximately 40% of global fuel-based emissions, stemming from embodied carbon emissions from building materials and construction and operational carbon emissions from active energy use. These emissions fuel climate change and its devastating consequences, disproportionately impacting vulnerable communities (Intergovernmental Panel on Climate Change [IPCC] 2022). This impact on climate change highlights the urgent need for drastic emission reductions from buildings to achieve climate goals (International Energy Agency [IEA] 2023). A dynamic intersection of policy, technology, and investment is crucial for tackling this challenge. Innovation and entrepreneurship in

clean energy and building technologies are emerging as promising solutions for scaled decarbonization of commercial and residential buildings. Unlike traditional approaches that often focus on incremental improvements, startups in this space have the potential for disruptive innovation, developing radical technological solutions and business models that can fundamentally transform how the built environment is designed, constructed, operated, and retrofitted (McKinsey 2023).

This study investigates how entrepreneurship and innovation frameworks–specifically for building and energy technology development and commercialization–can drive market transformation toward decarbonization and equitable development in the built environment. This publication is a five-year case study of IMPEL, a unique public-private incubator funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO) and implemented by Lawrence Berkeley National Laboratory (LBNL). IMPEL utilizes a public-private partnership since PPPs can help mobilize the private sector finance required to springboard public funding and enhance innovation systems and infrastructure systems that could address the impacts of climate change (UNFCC, 2021).

In the past few decades, climate-tech has seen boom-and-bust cycles. Venture capital firms invested in climate-focused ventures between 2006 and 2011, pouring over $25 billion into this era known as Clean Tech 1.0 (B. Capital, 2023). However, Clean Tech 1.0 ultimately faltered due to private investors' focus on capital-intensive and R&D-heavy sectors and not accounting for technology risk, development, and scaling timelines (Levin, 2023). External factors further complicated this, including the 2008 financial crisis, falling oil and gas prices, competition from Chinese solar products, and a decline in government subsidies, leading to a decade of decline in climate financing (MIT, 2023).

The landscape shifted again in 2018 with the emergence of Clean Tech 2.0, which gained momentum with a record-breaking $37 billion invested in the sector by 2021 (CTVC 2023). Cleantech 2.0 has the advantage of building on the Cleantech 1.0 research and development and groundwork for fundamentally new industries, including clean energy supply and energy-efficient materials and equipment for the built environment. However, in 2023, private investment for climate tech start-ups dropped by 30% compared to 2022 (CTVC 2023). Technologies with relatively higher emissions reduction potential are being expected to be funded by banks, governments, and other funders – not venture capital firms and private investors who back start-ups (World Economic Forum 2023).

The advent of the U.S. Inflation Reduction Act (White House 2023) is promising due to a critical diversification of the capital stack with public funding, with its intention of a $783 billion investment in energy and climate change that could unlock orders of magnitude of private investment. Additionally, the White House is focused on equity, along with the Justice40 Initiative, committed to delivering 40 percent of the overall benefits of climate, clean energy, infrastructure, and other investments to disadvantaged communities, including tribes, communities with environmental justice concerns, rural areas, and energy communities.

A dovetailing of public sector provisioning catalytic capital for equitable outcomes and private sector with its investment in innovative business models are required to overcome political and financial risk, volatility of financial markets and their complex and long-term nature, and continuously evolving markets.

This publication analyzes the IMPEL public-private incubator within the larger climate tech space. It provides insights on addressing critical barriers from technology, policy and regulatory, and capital and market perspectives that impede the scaled commercialization of innovative building technologies.

About IMPEL

IMPEL's theory of change is to advance a zero-carbon built environment that promotes equitable wellness by accelerating innovation and entrepreneurship (U.S. DOE 2023). This initiative aligns with the U.S. DOE's ambitious decarbonization strategy. The DOE aims to reduce building emissions drastically – 65% by 2035 and 90% by 2050. Notably, this strategy prioritizes equity, affordability, and resilience for communities.

IMPEL's scope extends beyond National Labs' traditional role of science discovery and technology inventions– to supporting innovation and entrepreneurship in clean energy and sustainability. The program aims to help founders navigate the challenges of wide gaps between early-stage R&D and commercialization-to-market through multiple "valleys of death" (Figure 1). IMPEL addresses these by providing commercialization training in the short term within the year of participation, access to grants, funding, and demonstration pipelines in the medium term (1-3 years after the program), as well as potential unlocking of long-term benefits (3-5 years after the program).

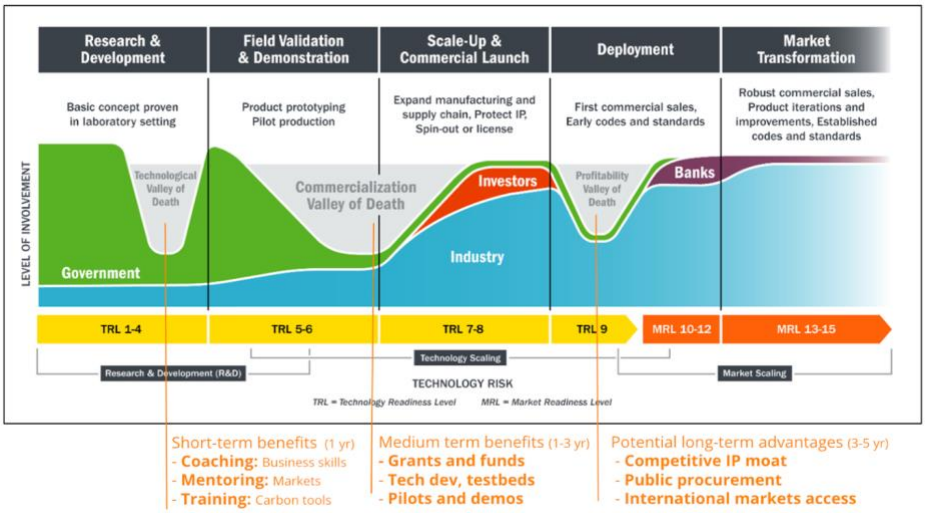

Figure 1. IMPEL's support of Innovators in their technology-to-commercialization journey (Source: DOE, 2021)

The following factors directly influence IMPEL:

- U.S. DOE-BTO goals shape the program's scope, growth, and focus each year. In recent years, an emphasis on zero-emission buildings (DOE 2023), technology deployment, and pilot demonstrations to provide technology derisking has emerged. Additionally, their strategy prioritizes equity, affordability, and resilience for communities.
- LBNL's goals are to advance energy efficiency, increase cost savings, improve equitable comfort, health, and safety in the built environment, and provide scientific validation of technologies that impact their selection and market uptake.
- Program feedback from current and past innovators through formal surveys and interviews
- Insights from IMPEL's Coaches on the innovative business models that may have a more robust market pull and lead to capital de-risking.
- Insights from IMPEL's Mentors on identifying investment gaps, scaling building technologies, and developing more robust incubator-stakeholder-market interactions.

Indirect influences on program growth and direction include:

- Federal and global policy, including the Infrastructure Investment and Jobs Act (2021), Inflation Reduction Act (2022), and the United Nations Climate Summit (2018-2023).

- Growing public awareness of climate impact on the quality of life, particularly for those included in historically marginalized and/or disadvantaged community groups.
- Investor opportunities focused on climate technology solutions gleaned from key market intelligence platforms for improving collaboration and coordination among investors across multiple stages of technology development and investment types.

How IMPEL operates?

IMPEL provides a comprehensive support infrastructure for a select cohort of early-stage innovators each year. The program leverages its access to technical resources, established buildings and energy stakeholder networks, and unique embedding in the National Lab ecosystem. Through rigorous recruitment and selection, IMPEL identifies high-potential innovators who benefit from the program opportunities in three phases: Foundational Training, Advancing Models, and Public-Private Pipelines, as shown in Figure 2.

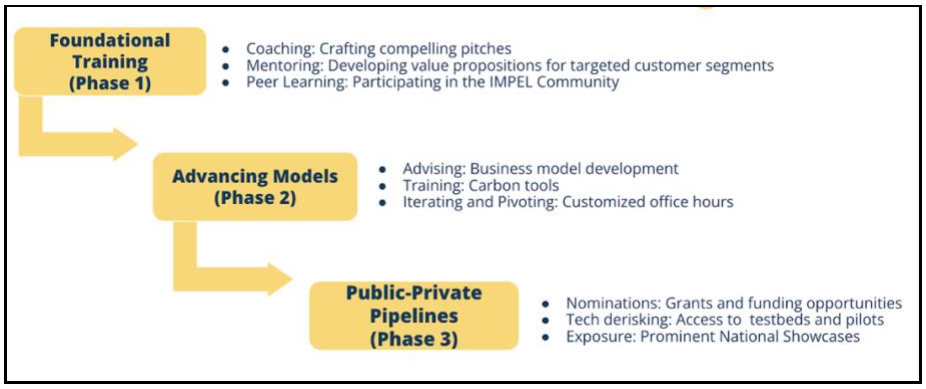

Figure 2. Phases of the IMPEL program's offerings for Innovators.

IMPEL Outcomes

IMPEL advances teams and technologies that are novel, scientifically robust, and emissions-reducing towards go-to-market–by enabling technology derisking, business model innovation, matching applications, and regions, and helping to address known and unknown barriers. It allows innovators to overcome critical obstacles, e.g., by helping attain first-of-a-kind financing through grants, bringing together the right teams, pilots, plans, and partners to accelerate building decarbonization. IMPEL has 28 active mentors who are investment, policy, demonstration, industry, and subject matter experts and entrepreneurs, as well as four key collaborating organizations across the public and private sectors that support the innovators through investor connections, funding opportunities, technical assistance, demonstration and pilot opportunities, and high-level exposure to networks.

IMPEL has grown significantly from five innovation teams in its pilot year to 250 teams in its fifth year. These early stage 'IMPEL Innovators' are building entrepreneurs, researchers, and professionals (Figure 3[1]) who have collectively raised over $125 million in non-dilutive and private funding. IMPEL Innovators have received over 200 awards, grants, prizes, and pilots, created over 200 additional green jobs, and launched three new building technology manufacturing facilities. Additionally, they have piloted and demonstrated heat pumps, water heating, and cooling equipment and made remote audits and retrofits more accessible.

[1] This figure is limited to self-reported numbers, and other funding, particularly private sources, are not always disclosed or shared.

The program has intentionally served a diverse pool of innovators, with 55% self-identifying as non-white, non-male, or BIPOC (Black, Indigenous, and people of color) and hailing from across 36 U.S. states and territories, significantly adding states that are not typically participants in the climate tech entrepreneurial ecosystem. Almost half of innovators are working on new hardware projects, such as building materials, systems, and equipment that have been traditionally difficult to commercialize.

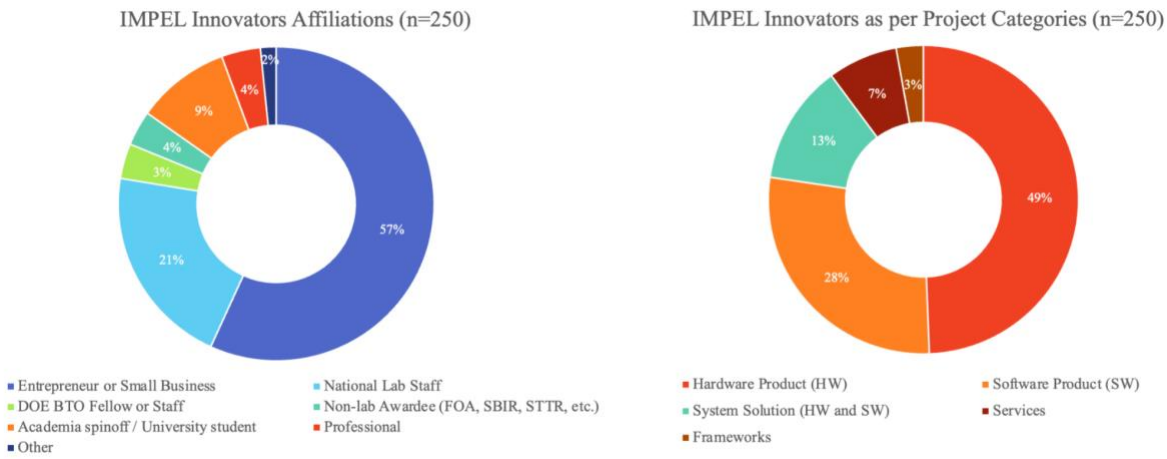

Figure 3. Types of Innovators Participating in IMPEL.

Methodology

The research questions for this study are:

1. What are the critical barriers that impede the commercialization of innovative decarbonization building technology, as encountered by stakeholders across the building value chain (industry: designers, builders, and operators; investors; product manufacturers and policymakers)?
2. What are the vital, common barriers that innovators developing building decarbonization technologies should address through their value propositions?
3. Using IMPEL's current ecosystem as a foundational base, is there an expanded market-forming framework that can leverage public-private technology-to-market entities to overcome the boom-and-bust cycles of private sector climate tech investing and any instabilities in public sector grant and policy environments and drive built environment decarbonization at speed and scale?

The methodology for this research included three aspects:

1. *Market landscape review:*
    a. Scope: We reviewed private innovation incubator/accelerator programs in the U.S. that support companies developing decarbonization and clean energy technologies.
    b. Process: We identified relevant incubator/accelerator programs through online databases, industry reports, and academic literature.
    c. Analysis: We analyzed IMPEL's positioning within this landscape to understand its unique contributions and potential areas for expansion.
2. *Data collection and analysis on the IMPEL ecosystem and portfolio are as follows:*
    Primary data collection on stakeholders' barriers:
    a. Participants: We engaged stakeholders from IMPEL's industry, innovation, investor, and knowledge networks.

b. Methods: We conducted 60 surveys and 15 semi-structured interviews to gain insights into their challenges and opportunities.
c. Survey/Interview Design: We developed questionnaires informed by a literature review to capture each group's unique perspectives and challenges.
d. Focus Areas: We explored the fragmented nature of the current landscape, where stakeholders often operate in silos with seemingly diverging values. This includes investors seeking impactful returns, established industries (building design, build, operate) grappling with adaptation, innovators (early-stage entrepreneurs) brimming with ideas but facing hurdles, and policymakers.

Secondary data collection on the IMPEL Portfolio of technologies:

a. Scope: We assessed the IMPEL portfolio of 250 innovators, focusing on team compositions, building technologies, technology readiness levels (TRL), and value propositions for targeted building industry off-takers.
b. Sources: We analyzed program reports, pitch decks, video recordings of IMPEL presentations, public data, and company websites to gather information.

3. *Data analysis and synthesis:*
   a. Thematic Analysis: We analyzed data to identify key themes related to financial, technology, policy, and market barriers.
   b. Process: We used coding techniques to identify patterns and recurring themes and synthesized them to gather insights for market transformation.
   c. Validation: We ensured the reliability of findings by cross-referencing with external data sources and conducting consistency checks.
4. *Gap analysis for a market forming framewor*k:
   a. Objective: We identified gaps in the current building innovation landscape that a potential market-forming framework for decarbonization building technologies could address.
   b. Analysis: We conducted a gap analysis highlighting areas where the current ecosystem falls short.
   c. Recommendations: We proposed a framework with a prioritized set of new activities to expand benefits and drive market transformation.

Results

Tech-to-Market Landscape Review and IMPEL's Positioning

To benchmark the IMPEL program, we compared prominent public or private incubator/accelerator programs operating in the U.S. that support climate technology companies, as shown in Table 1.

While several programs support early-stage founders or collaborate with government entities, few focus specifically on building technologies or offer training on using carbon calculation tools or technology. Notably, we also found that many of these programs take equity from participating companies. IMPEL is differentiated as the only accelerator program encouraging early-stage innovators across the U.S., taking no equity, explicitly focusing on climate technology specifically for buildings, and providing training for carbon calculation tools to help validate the technologies for their potential decarbonization impact. Additionally, IMPEL facilitates innovator access to public and private networks through its multi-year partnership with the incubator Greentown Labs and mentor ecosystem.

Table 1. Current U.S. public and private incubator-accelerator programs.

Programs		Funding	Serve early-stage teams	Equity	Barriers to entry for the program	Govt / Industry / Investment collaboration	Focus on climate tech companies?	Focus on building tech	Carbon calculation tools/tech training
PUBLIC	NREL Innovation Incubator	✓	✓	X	High	Govt, Industry	✓	X	X
	Chain Reaction Innovations	✓	✓	X	Medium	Govt, Investment	X	X	X
	Energy I-Corps	X	✓	X	High	Govt	X	X	X
	Cyclotron Road	✓	✓	X	Medium	Govt	X	X	X
	IMPEL	X	✓	X	Low	Govt, Industry, Investment	✓	✓	✓
PRIVATE	Activate Global Inc.	✓	✓	X	Medium	Govt, Industry	X	X	X
	Cleantech Open	X	✓	Possibly	Medium	Govt, Investment	✓	X	X
	Greentown Labs	X	✓	X	Medium	Govt, Industry, Investment	✓	X	X
	LA Cleantech Incubator	X	Unclear	Possibly	Low	Govt, Industry, Investment	✓	X	X
	Third Derivative	X	✓	Possibly	Low	Industry, Investment	✓	X	X
	Y Combinator	✓	✓	✓	Low	Industry	X	X	X

Stakeholder Barriers

Despite the undeniable need for widespread adoption of climate tech solutions, a complex web of interconnected issues and barriers hinders various stakeholders within the ecosystem. To gain deeper insights into these challenges and opportunities, we conducted surveys and interviews with 40 Innovators and 20 other key stakeholders, i.e., Investors, Industry (Design, Build, Operate), and 15 semi-structured interviews with Knowledge experts (Policymakers, National Labs) The results are summarized below.

Innovators from the IMPEL program: Young businesses, often grappling with a lack of experience and market access (Budden and Murray 2019; Gassmann, Enkel, and Chesbrough 2014), face difficulties attracting investment while navigating complex investor relationships (Clarkson, Decker, and Gordon 2017). Surveys revealed key challenges as well as some exciting opportunities (Figure 4) that are summarized as follows:

- *Financing barriers:* A high-risk perception is associated with building technology ventures and limited access to suitable investors. IMPEL Innovators with software products were generally able to raise private sector funding. Innovators who built hard tech articulated the

need for non-dilutive, patient capital for the longer time horizons required for development and commercialization.

- *Market and Policy barriers:* Gaining customer awareness and adoption has proved difficult for Innovators, fueled by a lack of incentives and standard codes nationwide (Figure 5) that could otherwise provide scalability potential for their technologies. Customer resistance to change emerged as the most significant barrier, followed by a lack of access to distribution channels.
- *Technical and operational barriers:* The challenge of integrating with legacy systems, particularly for retrofits, and the need for advanced R&D infrastructure were major hurdles in developing and implementing new climate tech solutions.

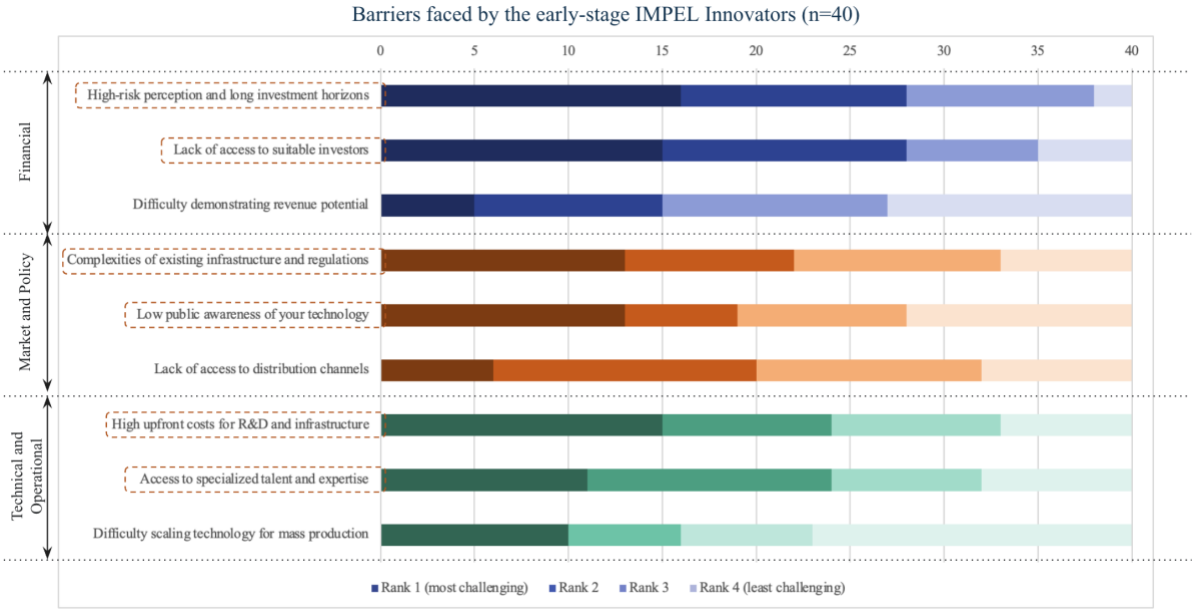

Figure 4. Barriers faced by early-stage building technology Innovators.

Despite the challenges, Innovators showed enthusiasm for a ‘portfolio approach’ for early cross-technology integration, i.e., the potential of "packaging technologies through a portfolio approach" for tackling climate challenges. 75% of respondents highlighted its potential for increased effectiveness and impact. Such a collaborative approach, which potentially integrates complementary technologies at the earlier stages where IMPEL Innovators tend to be, could improve cost-effectiveness and resource optimization (60% of respondents) and enhance innovation and creativity (40% of respondents). Some concerns regarding a potential portfolio approach were also identified, including time commitment, confidentiality, and intellectual property rights.

Investors: Investors seeking substantial returns on investment (ROI) are attracted to young businesses offering high-growth potential in a rapidly exploding market driven by the urgency of addressing climate change (Global Market Insight 2023). Additionally, by investing in climate tech, investors can contribute to positive environmental and social impact, aligning their investments with their values and attracting socially conscious investment partners. This impact investing approach allows portfolio diversification beyond traditional asset classes (Cohen, Winn and Hahn 2015). However, investors express concerns about managing risks associated with startup ventures and identifying high-quality ideas deserving of funding (Budden and Murray 2019). Our interviews with private sector investors (seed to series) revealed that they typically evaluate software companies based on metrics like growth, revenue, and customer acquisition. However, hard tech companies,

like many climate tech ventures, require a different approach due to the additional barriers associated with physical installation/integration, equipment supply chains, installer networks, etc.

Most respondents (80%) identified inadequate/policies and regulations to create a market pull or future market clarity as the biggest challenge in scaling. Additionally, a fragmented industry with disparate decision-makers across the value chain was a significant concern for 60% of the respondents. Interviews with investors further confirmed the challenging nature of the building tech sector, characterized by limited investment, market fragmentation, difficulty scaling solutions quickly due to a lack of standardization and replicability across markets, and integration with legacy infrastructure such as retrofits—the need for innovation drivers beyond corporate sustainability goals and potential tax credit compounds these challenges. There is difficulty demonstrating cost savings or conducting technical and financial due diligence at early stages. For climate tech investments, investors prioritize early-stage validation of the technology's core concept, demonstrable performance validation through pilots or prototypes, standardization and certification, and a clear market pathway with traction from early customers.

***Industry*:** Collaborations with Innovators can foster knowledge-sharing and capacity-building within architectural, engineering, and build-construction communities (Etzkowitz, 2003). Innovators offer architects and engineers access to new tools and approaches for sustainable design and construction. Innovators can also provide valuable market access and partnership opportunities for stakeholders like product manufacturers. Collaboration can lead to developing and commercializing new climate tech products, potentially creating new revenue streams and market opportunities for manufacturers (Chesbrough, 2011). By partnering with young entrepreneurs, manufacturers can access innovative technologies and solutions, potentially leading to a competitive advantage in the market (WBCSD, 2020). This can help them stay ahead of the curve and cater to the growing demand for sustainable products driven by increasing consumer awareness and environmental concerns.

The industry experts identified three key barriers to integrating innovative climate technologies into building design and construction. The first is a limited awareness of available solutions. Half of the respondents within the building industry highlighted a need for knowledge about existing climate tech options, hindering their ability to incorporate them into projects effectively. The second is uncertain performance standards for new technologies. A lack of clear benchmarks for measuring the effectiveness of new technologies creates hesitation and makes it difficult to choose the most suitable solution. The third key barrier is a perceived lack of return on investment. Developers and builders are reluctant to adopt any new product changes, particularly given the higher upfront costs and the owner-tenant split incentive issue, i.e., if the tenant is paying the utility bills, the owner has no incentive to invest and pay for the improvements that would save the renter on their utility bills. The survey also revealed concerns regarding technical complexity and system integration, limited financial incentives for clients, and the availability of skilled professionals for installation and maintenance. Interestingly, this group believes that innovative materials and construction methods for low-carbon and resilient buildings hold the most promise for future building decarbonization efforts. However, successful technology integration relies heavily on additional factors such as reduced upfront costs, user-friendly interfaces, and reliable maintenance and support to successfully integrate climate tech solutions.

Knowledge Creators and Policymakers: National labs and Universities struggle to bridge the gap between research and commercialization and keep their curriculum and R&D aligned with rapid advancements (Etzkowitz 2003). Policymakers face challenges in developing effective, standardized, and equitable policies that incentivize adoption while navigating complex political landscapes (Mowery 2011; Ursprung Lin, and Renn 2020) at federal and regional scales. Through their on-the-ground experience and innovative solutions, innovators can provide policymakers with

valuable data and insights into the feasibility and effectiveness of climate tech solutions. With support from DOE tools and national labs experts, IMPEL's training/standardization on carbon calculations empowers innovators with better transparency on emissions reduction in a space fraught with greenwashing. This can help inform the development of policies supporting these technologies' adoption and scaling (World Resources Institute, 2023). Innovators can also be crucial in fostering public engagement to build essential public support for climate action and policy measures that accelerate the transition to a sustainable future.

The survey with knowledge experts and policymakers at national and local scales suggests that incorporating existing standards and test procedures to be more suitable for accelerating startup technology development and providing access to government support, such as validated testing facilities and non-dilutive funding, is crucial. Policymakers should focus on creating an environment conducive to commercial success.

We synthesized the results and identified common critical barriers across the stakeholders that are necessary to overcome for adopting and scaling new technologies as follows (Figure 5):

- *Financial barriers* due to higher (perceived) costs of the new technology and required human capital services compared to business-as-usual, and overall investment risk. Bridging the funding gap by dovetailing patient, non-dilutive capital from banks and governments to de-risk technologies and production at the earlier stages and private capital for funding go-to-market and business model innovation at the later commercialization stages is critical.
- *Market and policy barriers* include a fragmented building value chain, insufficient awareness of and availability of new decarbonization products, and a need for uniform codes, streamlined incentives, and permitting.
- *Technology and operational barriers exist,* and more technical and cost data is needed to validate performance and carbon impact. These challenges are compounded by challenges in integrating with legacy systems, distribution channels, and infrastructure.

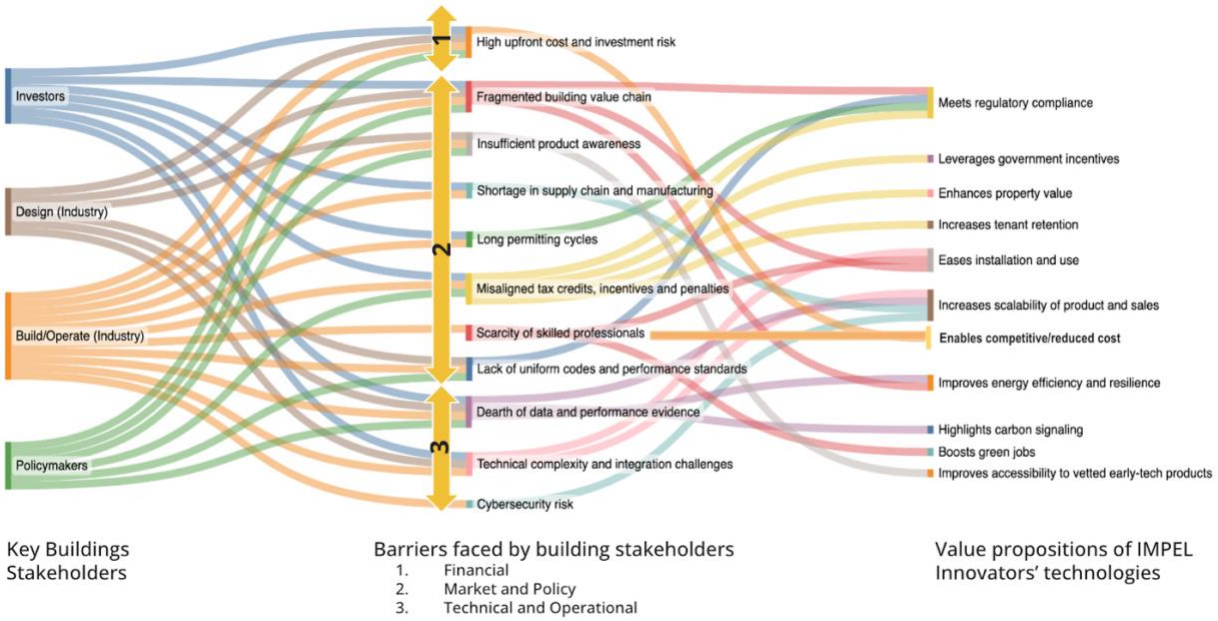

Figure 5. Barriers faced by key building stakeholders, and value propositions of IMPEL Innovations.

We analyzed the recorded pitches from Innovators participating in IMPEL and their value propositions for their target customers. The study revealed that the IMPEL portfolio of technologies can offer significant energy benefits, such as improving energy efficiency and resilience, as well as

key value through non-energy benefits (Figure 6) to address the abovementioned barriers. The IMPEL technology portfolio can scale the decarbonization agenda by:

- *Being responsive to regulations and markets* by providing data around product performance and emissions reduction potential, current or future code compliance, avoiding penalties, and leveraging incentives and rebates, especially across various regions—these factors address market, policy, and financial barriers. This relates to IMPEL Innovators' key value propositions: meeting regulatory compliance, leveraging government incentives, and improving accessibility to vetted early technology products.
- *Being easy to use,* as compared to incumbent technologies and services, by reducing the complexity of design, installation, use, and maintenance, with reduced construction or downtime, and the ability to be integrated with any legacy systems – these factors address technology and operational barriers. This relates to IMPEL Innovators' key value propositions: easing installation and use and boosting green jobs.
- *Being cheaper and revenue-generating* by being price-competitive, viz., current technology (or doing nothing), reducing first or operational energy costs, rapid use for user time savings, and enhancing property value and tenant retention—these factors address financial barriers. This relates to IMPEL Innovators' key value propositions: easing installation and use, enabling competitive/reduced cost, enhancing property value, increasing tenant retention, and increasing the scalability of product and sales.
- *Being better* by providing benefits such as ‘delightful’ user interfaces, enhanced wellness and environmental comfort, behavior change, and durability and disaster resilience. This relates to IMPEL Innovators' key value propositions: highlighting carbon signaling and improving resilience.

IMPEL Portfolio Approach

Next, we analyzed the technologies incubated over the five years to categorize and understand the IMPEL technology portfolio. As a first step, we categorized using technology readiness levels (TRLs) (Figure 6). We noted that over the five years of IMPEL, there has been a gradual shift to higher TRL technologies. This may result from both the enhanced programming of the incubator, attracting more mature innovators, and a market shift with the relative increase in climate tech funding advancing technology development.

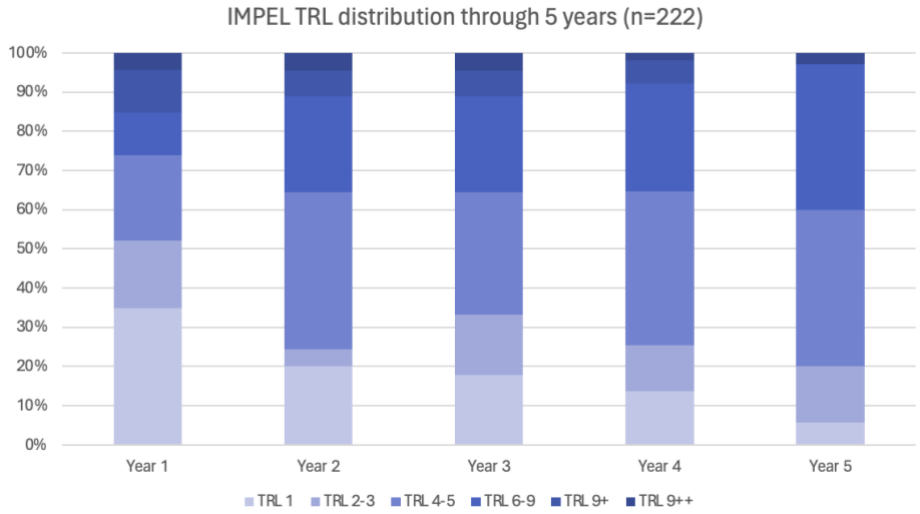

Figure 6. Distribution of IMPEL technology portfolio by Technology Readiness Levels (TRLs).

We then categorized the portfolio by type of technology. The type indicates whether the technology is a building physical system for its lifecycle, e.g., design, construction, operations, and circularity, a buildings-edge system, e.g., onsite renewables, energy storage, electric vehicle charging, and grid integration incorporating electrification, or a digital system, e.g., simulation, automation, monitoring, control and optimization systems, and procurement software platforms (Figure 7).

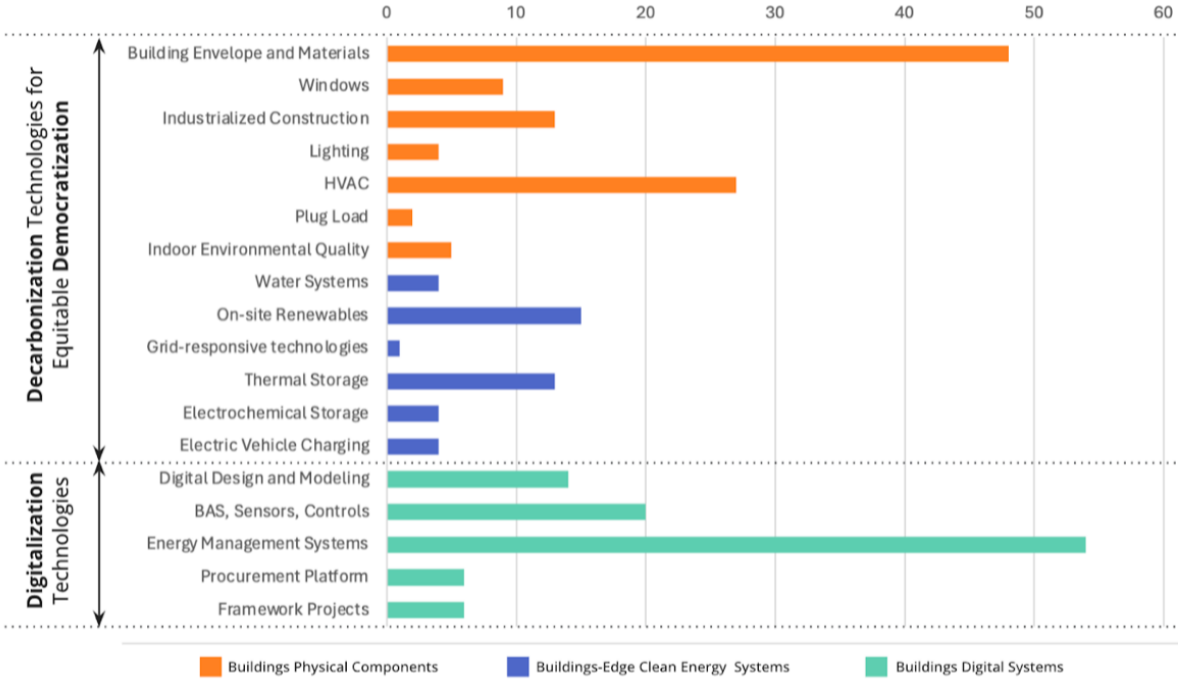

Figure 7. Distribution of the IMPEL portfolio by impact areas.

Our study showed that the IMPEL technology portfolio has a positive impact on the built environment as follows:

- *Decarbonization* of the built environment through vetted products such as low-carbon materials, construction assemblies, equipment, and operations, i.e., through embodied and operational carbon reduction and circularity of materials and energy flows.
- *Digitalization* through digital tools and technologies to support integration, management, and optimization of buildings, clean energy systems, and the grid.
- *Democratization* of technologies to enable equitable access to health and wellness in the built environment.

This analysis suggests strategic stage-wise innovation clustering opportunities may exist for off-takers along the buildings' value chain. These off-takers are potential buyers of building decarbonization technologies, which may be region-specific or typology-specific, i.e., commercial/single-family/multifamily housing. The off-takers may include – planners, architects, and engineers who specify the technology into their projects at the design stage; contractors, builders, and developers who install the products at the build stage; and facilities and utilities managers and owners who use the products at the operate stage. A key opportunity is to transcend beyond the one-off startup support that IMPEL currently provides and create many-to-many engagement opportunities. These engagements between clusters of innovators servicing specific stages of the building value chain and the off takers may accelerate market adoption of new

technologies to enable the entire ecosystem's success (Figure 8). A robust market network of innovators, industry, and investors would need to galvanize effective many-to-many engagements.

Additionally, there may be opportunities for technology packages through new partnerships between younger, agile companies. Conceptually, component technologies from different startups may pair into a system such that the whole is greater than the sum of its parts. For instance, a decarbonization-as-a-service company could partner with implementable on-site technologies as part of its portfolio of decarbonization solutions. Another example is that a software startup could pair with a hardtech startup to form a novel solution.

In future work, we could cluster and strategize the advancement of technology clusters and technology packages for commercialization.

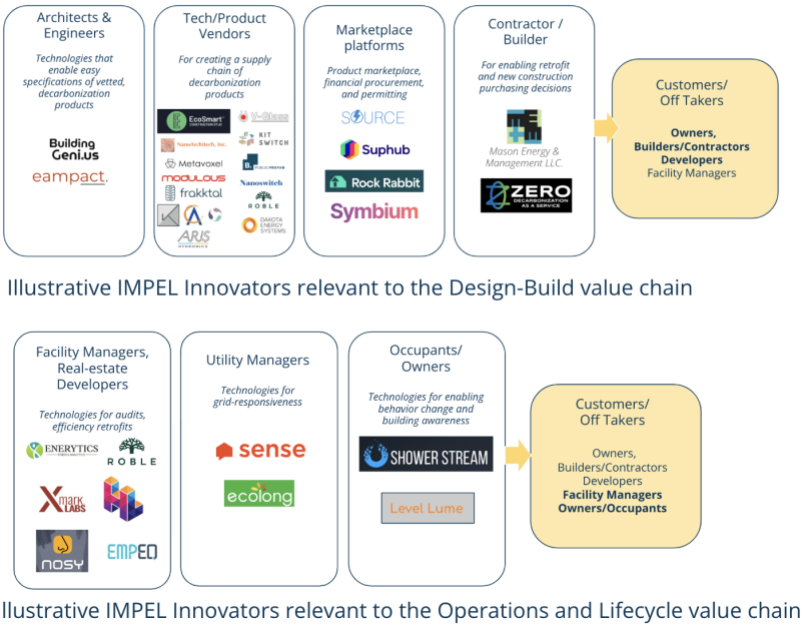

Figure 8. Illustrative IMPEL portfolio technologies showing relevance to the buildings value chain.

Discussion: A Market-Forming Framework

Innovators can benefit the building ecosystem by fostering collaboration and public engagement and addressing the barriers we present here. A framework where key stakeholders can align through an industry, investor, innovator, and knowledge network (I3KN) can provide a robust market-forming framework to accelerate toward a sustainable future. An I3KN can help:

1. *Bridge the funding gap* by connecting Innovators with suitable investors and grant organizations who understand climate tech ventures' unique challenges and opportunities to support capital derisking. This can strengthen the ecosystem of climate innovation across the investment landscape by building investor capacity to evaluate, select, and fund nascent climate technologies effectively; better-aligning risk and return metrics with investor capabilities and start-up needs; and enhancing non-financial support, such as expertise, partnerships, connections, equipment, and political advocacy (BEY 2019).
2. *Foster collaboration between innovators and established industries* to facilitate technology derisking and adoption at speed and scale, IP licensing and partnering, and accelerating the integration of novel solutions into new and legacy systems. Many-to-many engagement opportunities to connect innovators with off-takers from the industry are vital to the success of the buildings ecosystem and driving critical decarbonization.

3. *Inform policy development* by providing policymakers with data-driven insights from on-the-ground experience, enabling the creation of policies that support the widespread adoption and scaling of climate tech solutions. Here, IMPEL's standardized training/tools for carbon calculations could be fundamental to the I3KN structure.

Conclusion

This research paper focuses on the landscape of climate tech advancements to decarbonize the complex-built environment. While individual actors–innovators brimming with ideas, established industries with vast resources, and policymakers wielding the power to shape supportive frameworks–all play crucial roles, their efforts often operate in isolation, hindering progress.

The IMPEL program demonstrates the immense potential of innovation and entrepreneurship in driving the transformation of the building sector towards a zero-carbon future. By nurturing a diverse pool of early-stage innovators and fostering collaboration across the ecosystem, IMPEL has empowered young businesses to develop and commercialize groundbreaking building technologies.

However, significant hurdles persist. Fragmented markets, a lack of standardized codes and incentives, and the high upfront costs of new technologies hinder widespread adoption. Overcoming these barriers requires a multi-pronged approach. We recommend a market-forming framework, i.e., an Industry, Investor, Innovator, and Knowledge Network (I3KN) for developing powerful public-private technology-to-market initiatives in service of a zero-carbon built environment. This framework can provide resilience against the boom-and-bust cycles of private sector climate tech investing and any instabilities in public sector grant and policy environments to drive built environment decarbonization at speed and scale. Such an I3KN may be harnessed for stakeholders to leverage each other's strengths and overcome these challenges.

The benefits may include de-risking technology and teams, de-risking capital, connecting innovators with investors who understand the long-term value proposition of climate tech ventures, accelerating adoption by facilitating collaboration between innovators and established industries to integrate new technologies into existing systems and informing policy-making by providing policymakers with real-world data, and on-the-ground experiences to Innovators and Industry to develop effective policies that support market transformation.

The IMPEL program is a successful model for fostering innovation and collaboration in the built environment. Scaling up such initiatives and promoting a robust I3KN can unlock the full potential of clean energy and building technologies to create a more equitable and sustainable future. Collaboration and coordination within the I3KN, across investment stages and technology development phases, can help bridge the "valleys of death" in climate tech finance and navigate the complexities of political and economic cycles. While challenges remain, the potential benefits of a collaborative I3KN are undeniable. Such a collaborative approach presents an essential pathway for tackling the climate crisis. Through a collective effort, we can bridge the gaps between innovators, investors, industries, and policymakers, paving the way for a decarbonized built environment.

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