A Roadmap to 10x: Increasing the Production and Affordability of "Climate-Ready" and "Climate-Friendly" Homes in California

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ABSTRACT

California is already falling behind on its goal of creating 7 million "climate-ready" and "climate-friendly" homes by 2035. To catch up, and to close the gap on housing affordability, it must find a way to deliver housing that is radically cheaper, faster to build, and more resilient--with greater reliance on locally sourced materials and manufacturing. Current practices for housing production are notoriously slow, energy-intensive, environmentally unsound, and unaffordable to the majority of Californians. As climate change factors continue to elevate risks such as wildfires, heat stress, and water scarcity, the need to explore the application of factory built, high-performance housing has never been greater. This paper presents an analysis of past efforts and emerging innovation in design for industrialized construction with a focus on Zero Net Energy all-electric homes in Southern California. The paper outlines the system changes needed to establish a "10x" target as the benchmark for rethinking housing delivery across design, approvals, manufacturing, installation, financing and workforce development.

Introduction

California's already critical housing shortage has been made worse by wildfire destruction. The housing gap is driving the affordability crisis, with the California median home price more than double the U.S. national median (CAR 2026, NAR 2026) and rents among the highest in the nation (Zillow 2026, CalMatters 2024). To address the housing gap, the state has mandated planning for over 2.5 million new homes by 2031, with at least 1 million designated for lower-income households under the current Regional Housing Needs Allocation (RHNA 2023-2031) cycle (HCD 2022). This translates to over 350,000 units needed, annually, to meet the current RHNA target - a rate the state has never reached in its history. Between 2022 and 2025, California added only 364,000 new housing units, approximately 121,000 units/year, or 1/3 the target production rate.

Policy makers and practitioners are faced with the challenge of facilitating an unprecedented increase in the rate of homebuilding, while simultaneously making housing units more affordable, environmentally sound, and climate resilient. The building sector is the state's second largest source of greenhouse gas (GHG) emissions (after transportation), accounting for 25% of the state total when accounting for both on-site fossil fuel combustion and the combustion of fuels offsite to generate electricity (Kenney et al. 2021). California's goal to produce "climate-friendly" housing refers to homes designed to incorporate high-efficiency electric end-uses and on-site renewable energy systems in support of the broader statewide goal of carbon neutrality by 2045. The term "climate-ready" refers to housing designed with increased resistance to extreme heat, wildfires, power safety shut-offs, and with improved ventilation systems and the capacity for energy storage (battery storage).

In addition to low housing production volumes, the state is currently projected to fall 2 million units short of its 6-million-unit heat pump adoption goal by 2030 (CAHPP 2025). Adoption rates remain low: 20% of HVAC sales for heat pumps and only 3-5% for Heat Pump Water Heaters (HPWH) (CAHPP 2025). Increasingly strict energy code (Title 24-6 2025) favors the replacement of natural gas with heat pumps, but it fails to mandate heat pump adoption. Higher first costs, low consumer awareness, and lack of familiarity by local jurisdictions during plan review and on-site inspection all contribute to barriers to adoption, along with the lack of training and project experience in design, installation, commissioning, and maintenance.

While California seeks to ramp up home production, it is delaying the onset of code updates intended to drive higher levels of efficiency and decarbonization. California Assembly Bill 130 places a six-year moratorium (October 2025–June 2031) on new residential building code updates (California Legislature 2025). The moratorium is designed to provide regulatory certainty by freezing state and local code changes that can otherwise trigger redesign costs, delays and approval uncertainty for pipeline projects. However, elimination of the 2028 energy code update cycle means that stricter statewide efficiency baselines and all-electric requirements for new housing will be delayed until at least 2032, resulting in a significant delay in California's residential electrification and decarbonization timelines. Unlocking an unprecedented increase in the rate of housing production while continuing to progress towards and equitable clean energy transition requires rethinking the conventional site-built approach and the larger ecosystem of design/planning, regulatory, financial, infrastructure, labor and supply chain components that support it.

Limitations of Site-Built Housing Production for Decarbonization

Although some estimates indicate that constructing an all-electric home in California can be less expensive than a conventional, dual-fuel home (Mahone et al. 2019, Fathollahzadeh et al. 2022, Kosmala-Dahlbeck et al. 2025), the perception remains that adoption of "beyond-code" electrification and efficiency measures leads to increased construction costs. This perception is understandable when observing the incumbent model of housing production, where the cost impacts of high-efficiency electrification are significantly shaped by the inefficiencies and fragmentation of conventional site-built housing production. Key structural barriers, and their impact on cost and decarbonization are outlined in Table 1.

Table 1. Key structural barriers and their impact on housing cost and decarbonization.

Structural Barrier	**Effect on Housing Cost and Delivery**	**Implication for Decarbonization**
High and non-transferable design costs	Architecture, engineering, permitting, and compliance activities can account for a large share (up to 40%) of project costs and are untransferable to the next project.	Each new efficiency or electrification requirement can trigger redesign and new documentation, reinforcing the perception that higher-performance standards increase housing costs.

Fragmented and inconsistent regulatory and compliance processes	Varying requirements across climate zones and local jurisdictions require customized design responses. Unpredictable approval timelines, and extensive on-site inspections.	Energy and electrification measures are implemented through complex compliance pathways, making code updates appear administratively burdensome and politically difficult.
Limited digitization and low-fidelity design coordination	Fragmented information flows and incomplete design coordination can lead to poorly integrated systems, inefficient equipment sizing, and construction delays.	Systems optimization and integration require coordinated design and performance modeling; weak digital integration increases cost and leads to on-site decision-making which often reduces efficiency.
Workforce and construction process constraints	Skilled labor shortages, irregular project delivery, variable trade contractors, and limited opportunities for process learning slow construction and increase costs. Lack of certainty for material and labor costs. Extreme heat and other on-site factors increase risk to workers and disrupt project timeline.	New technologies require specialized installation knowledge; limited workforce capacity, both in-office and on-site, can increase costs and slow adoption of decarbonization technologies.
Inconsistent quality control in site-built construction	On-site installation of insulation, air sealing, and mechanical systems is difficult to verify consistently, which can contribute to higher utility and maintenance costs.	High-performance building envelopes and electrified systems depend on precise installation; inconsistent construction quality can undermine expected energy savings.
Slow and disruptive construction processes	Site-built projects require comparably longer project timelines, create more noise and environmental disturbance on-site, and generate between 20-90% more waste. (WRAP, 2007)	Slow project delivery delays turnover of the housing stock toward lower carbon new construction and deep energy retrofits, slowing progress toward statewide climate goals.

Wildfire Rebuilding Context

The problems with current housing production are further exacerbated in the context of large-scale rebuilding efforts after natural disasters. The January 2025 Los Angeles wildfires resulted in 31 direct deaths, the destruction of over 16,000 structures (Cal Fire 2025) and capital losses estimated at up to $131 billion (Li and Yu 2025). Rebuilding is a slow and costly process. A surge in demand for permit approvals can slow permitting cycles due to staffing constraints. Rebuilding costs can increase because demand for regional labor and materials surges while supply is constrained. Increasing post-disaster construction costs, in turn, further widen the Insurance-To-Value (ITV) gap for homeowners trying to rebuild (Cotality Analytics 2025). A 2025 analysis by the Los Angeles Times found that just 38% of homes have been rebuilt from the five most destructive wildfires from 2017 to 2020 (Smith and Luna 2025). Toxic chemicals released during fires create hazardous job-site conditions for work that can be done more productively off-site. Electricity costs are further increased due to rate increases authorized to cover wildfire prevention (Helper 2024). New fire maps have expanded Fire Hazard Severity Zones, requiring nearly 4 million Californians to rebuild to heightened, more expensive fire-resistant building codes (OSFM 2025).

Disaster recovery is currently a barrier, rather than an opportunity for advancing the state of the art for housing production and advancing decarbonization goals. Executive orders such as N-29-25 which "*suspend rooftop solar and battery storage installation requirements and the 2025 California Building Standards Code"* (State of California 2025) reflect the perception that installation of advanced electrification, rooftop solar, and battery storage will increase overall costs and slow the process of construction. These outcomes highlight the need to broadly reexamine the current housing production model. This does not mean that climate-ready features are inherently incompatible with rapid recovery. Rather, it suggests that advanced energy, ventilation, resilience, and fire-hardening measures are more likely to support rapid rebuilding when they are pre-engineered, pre-approved, and repeatedly delivered as part of a productized building system.

A Brief History of Industrialized Construction in California

California has a history of homebuilders applying mass-production techniques, assembly line methods and economies of scale to address a shortage in affordable housing. One notable example is the postwar (1950-53) development of Lakewood, CA, where a mobile production line was used to produce and deliver "pre-cut," "keyed" packages of lumber to standard-sized building sites organized at a neighborhood scale. These standardized building components were installed in 45-days, resulting in the construction of 17,000 homes in three years. A wider variety of design solutions was shown to be achievable using factory-built, panelized components as a generative system. The complete home was flat-packed and delivered on a single vehicle to the site and assembled using a universal interlocking joint connector created by General Panel Corporation (GPC). GPC's 234,000 sq ft factory, mortgaged by the War Assets Administration, was equipped to produce 10,000 housing units a year on a single shift, although it never reached this goal (Herbert 1984).

A lack of customization and the homogeneous and repetitive appearance of the neighborhoods built using post-war production homebuilding methods, regulatory barriers, lack of large capital investments to stand up factories, reluctance of builders to adopt new methods, along with the disappearance of federal incentives for homebuyers, are all factors contributing to the failure of post-war production homebuilding efforts. The end to federal subsidies limited the pipeline of projects needed to sustain GPC's factory-built model, leading to bankruptcy and liquidation in 1952, with only about 200 homes built (Herbert 1984).

Today, the total market share of modular and panelized single-family homes is only about 3% (U.S. Census Bureau n.d.). Of the 450,000 multifamily units completed nationwide in 2024 (U.S. Census Bureau 2024), approximately 7%, or 31,500 units were built using off-site methods, which would meet less than 1% of the US estimated existing housing shortfall of 3.7 million units (Freddie Mac 2024). However, a growing number of multi-family housing projects in California are applying off-site, modular techniques driven by local housing incentives and factors such as challenges with workforce shortages and a lack of locally available workforce housing (Berg 2025). In Los Angeles County, a range of approaches have been deployed in response to programs designed to provide permanent supportive housing (PSH) for individuals experiencing homelessness. Approaches include stacked shipping containers (Los Angeles City Council District 8 n.d.), wood-framed “kit of parts” models designed for typical urban lots (BSH n.d.), tiny home villages (Lehrer Architects LA. n.d.), and novel panelized systems (LifeArk n.d.). In addition to PSH projects, Executive Directive 1 (LA DCP n.d.), initiated by Los Angeles Mayor Karen Bass, is designed to accelerate the development of affordable housing using repetitive unit types and the elimination of on-site parking requirements. While modern factories enable greater levels of customization to meet individual client needs, the industry base remains small and the industry as a whole lacks strong incentives to drive energy efficiency or electrification efforts beyond code requirements.

The most important U.S. precedent for rapid factory-built housing scale-up is the mobile-home / manufactured-housing production boom of the 1960s and early 1970s. This precedent should be separated from current debates over whether today’s U.S. Department of Housing and Urban Development (HUD) Code manufactured homes satisfy California’s energy, electrification, and resilience objectives. Its relevance is not that the historical product matches California’s current climate-ready housing standard. Its relevance is that the industry demonstrated the ability to scale factory-built housing production rapidly when manufacturers could serve broad markets with repeatable products. Falcettoni, Schmitz, and Wright (2024) find that mobile-home production increased from roughly 100,000 units per year in 1960 to 600,000 units per year in the early 1970s, reaching approximately one-third of U.S. single-family housing production. They attribute this scale-up in part to broader code geographies that enabled factories to produce standardized products for larger markets, justify investment in specialized machinery, and capture productivity gains through repetition and supplier learning. The lesson for California is therefore not to adopt HUD Code housing as the end-state solution, but for California to build a higher-performance version of that scale logic.

Prior studies from the National Laboratory of the Rockies (NLR 2022, formerly NREL) and Donnovan et al. (2022) demonstrate significant potential for deep energy reduction and cost savings by applying modular construction at scale. The NLR’s Energy in Modular (EMOD) Buildings Method articulates three primary strategies to integrate energy efficiency (EE) strategies into industrialized construction (IC) with the goal of avoiding increases in cost, labor or production time. They are, 1) streamline workflows through integrated product design to manufacturing, 2) building energy modeling and process productivity modeling, 3) cost compression through prototyping and process improvement (Pless S. et al. 2022). The EMOD method is intended to be generalizable to a wide range of building typologies and adaptable by industry. Synthesizing lessons learned from ongoing Zero Energy Modular (ZEM) programs and installations in Vermont, Massachusetts and Delaware, Donnovan et al. (2022) outline four key strategies for scaling ZEM, 1) lean manufacturing, 2) maximizing construction in the factory, 3) embedding support for factory construction in programs, and 4) supporting increases in the number of factories. The authors report that (as of 2022) only a fraction of the 1% of new construction built in a factory is built to a ZEM standard, demonstrating the potential to scale high performance IC has yet to be realized (Donovan et al. 2022).

A Roadmap to 10x

The following roadmap organizes the system changes needed to scale up home production in California by a factor of 10 while meeting statewide goals for "climate-ready" and "climate-friendly" homes.

1. Build regional capacity and coordination. The transition to design for manufacturing techniques and industrialized constriction— where standardization, integrated design, process innovation, and economies of scale can be leveraged to continuously improve performance while reducing cost, is only possible at scale by building support among a structured group of stakeholders to collaborate across regional boundaries to address shared interests and challenges. For example, Los Angeles County alone has 88 individual cities, most of which have their own building and safety departments, each with its own permitting requirements and processes. Replacing fragmented processes with regulatory reciprocity can enable a predictable, regional demand pipeline, providing manufacturers the level of market certainty needed to invest in factory modernization and workforce scaling. Beyond regulatory streamlining, regional coordination is needed to develop replicable contracting procedures and financing models, share project data, establish cost and performance benchmarks, facilitate peer-to-peer learning, collaborate on research and training initiatives, share best practices, and communicate effectively with community stakeholders and the general public (among numerous other benefits). The 1960s mobile-home production boom demonstrates that factory-built housing (FBH) can scale quickly when manufacturers can serve broad markets with repeatable products. California's challenge is to reproduce that production logic while raising the performance bar for energy efficiency, electrification, wildfire resilience, long-term durability, and resident quality of life.

2. Unlock fair access to housing by reducing production and occupancy costs while continuing to advance energy and decarbonization goals. Design concepts are needed that provide a pathway to homeownership for low-and moderate-income thresholds while still delivering on California's climate and resilience goals. State and Federal measures aimed at increasing the deployment of modern manufactured housing, including housing governed under HUD Code, are important affordability tools. However, increasing the supply of HUD Code homes alone is insufficient to meet California's combined housing, energy, and resilience objectives. Local zoning restrictions, financing limitations, site and building typology constraints, and product-performance requirements all remain barriers to implementation at scale. Furthermore, the Federal energy efficiency standards that HUD Code homes are designed to meet are less aggressive than California's energy efficiency and decarbonization goals. California should therefore build on the production-scale lessons of manufactured housing while requiring performance pathways that address electrification, solar and storage readiness, wildfire resilience, ventilation, installation quality, and long-term energy burden.

When considering the growing energy burden (the percentage of household income spent on energy bills) faced by tenants and homeowners, which disproportionately impacts low income households (Drehobl et al. 2020, Ayala and Dewey 2024), high-efficiency building electrification has the potential to reduce occupancy costs through reduced energy costs, with additional cost savings possible with high-efficiency vehicle electrification (Huether, 2024) and access to convenient low-cost charging (Kandhra et al. 2024). When additionally considering rising insurance costs, (or un-insurability limiting access to financing) additional cost reduction can be achieved from enhanced seismic, wildfire, and climate resilience.

3. Improve design flexibility with increased digitization and customizable product platforms. Another significant barrier to the widespread adoption of FBH is the perception that standardization inherently produces buildings of poor quality and lacking design flexibility. One can argue that this perception originates, in large part, from the negative cultural stigma surrounding manufactured housing (i.e., mobile homes) produced prior to the implementation of construction quality standards regulated by the U.S. Department of Housing and Urban Development (HUD), which were first implemented in 1976 (HUD, 1976). While modular housing is not governed under HUD and must perform in accordance with the same state and local building code requirements as a traditional site-built housing, like manufactured (HUD) housing, FBH must address the logistical constraints of roadway systems, current factory production methods, and on-site delivery processes. These additional constraints often lead to a limited set of pre-approved design options. However, this outcome is not an inherent feature of FBH. Many processes of FBH have yet to be fully optimized. Limited adoption of high-fidelity building information modeling (BIM), parametric design systems, and digitally integrated fabrication workflows has constrained the ability of industrialized housing systems to support variation while maintaining standardized production processes. FBH producers are, to varying degrees, transitioning to digitally enabled design-to-manufacturing pipelines, making it possible to implement principles of mass customization, where housing products are developed as configurable platforms composed of standardized components that can be arranged in multiple ways without requiring bespoke redesign. Such approaches allow variation to occur through parameter changes and component selection rather than entirely new design processes, thereby enabling customization without significantly increasing design costs.

Flexibility is needed at multiple scales, but it should be disciplined rather than unlimited. At the unit scale, configurable layouts and adaptable building systems can help producers respond to different household types, market demands, and affordability needs, such as studios, one-bedroom units, family-sized units, accessibility requirements, and changing customer preferences. At the project and site scale, producers seeking to serve urban infill, multifamily, mixed-use, or missing-middle markets must also account for varied building forms, irregular sites, climate zones, local design expectations, transportation constraints, and code requirements. These challenges are not unique to multifamily housing, but they become more difficult as projects become denser, more site-constrained, and more programmatically complex. Industrialized housing systems that operate as configurable platforms—rather than fixed products or one-off designs—are therefore more likely to support customization while preserving the repetition needed for factory production.

4. Capitalize on co-benefits of increased design hours. The acceleration of home production by advancing IC should not be viewed narrowly as a vehicle to drive decarbonization. The significant increase in design hours, performance modeling, and standardized testing afforded to develop innovative product platforms offers an opportunity to advance related goals. These goals include improved fire resistance, cost-effective water efficiency and reuse, environmentally-sound material substitutes (United Nations 1992), improved indoor environmental quality and other factors where limited design innovation can be achieved on an individual project basis and where additional cost savings are delivered either directly (e.g., lower property insurance, water and sanitation bills) or indirectly (reduced health costs due to improved indoor air quality or reduced exposure to heat-related health risks).

5. Adopt community-facing engagement methods, establish regional housing needs and priorities. Cross-jurisdictional collaboration and partnership building is needed, which extends beyond productized modular producers and associated investors. It is critical for local communities, particularly those most impacted by the housing affordability crisis, rising energy costs, and climate hazards (among other factors) to be empowered and engaged in shaping and validating proposed housing solutions. Establishing procedural equity, through initiatives to identify and characterize community-based regional housing needs and planning/land use priorities, is a critical first step for FBH producers to establish the social license to operate at scale.

6. Planning and land use changes to increase physical capacity for affordable housing. History has shown the viability of FBH is highly sensitive to production cycles. Designs that are cheaper to build are a fundamental strategy to grow the project pipeline for FBH by growing the market. However, future projects, particularly projects in the climates most suitable for low-energy buildings, are limited by a legacy of zoning and land use decisions preserving low-density single-family housing that remain largely intact. Planning and land use changes need to take place to create the capacity for more housing and to support zoning for low rise development (Dyett & Bhatia 2025).

7. Design for retrofitting, disassembly and reuse. Extending the application of productized (packaged) IC solutions beyond new construction projects offers the opportunity for additional market growth, both at the level of individual structures, where deep energy retrofit measures can be applied as a single packaged solution, as well as at the parcel level, where recent land use changes enabling multi-unit development on existing single-family-zoned lots (e.g., SB-9) can enable factory-built units to be installed alongside existing structures and interconnected to deliver high-efficiency electrification, on site renewables, and storage to the site without substantial disruption to existing residents.

8. Innovative financing. A significant barrier to realizing the construction timeline reductions associated with factory-built housing is the need for developers to commit significant capital early in the project lifecycle (HUD 2023, Enterprise Community Partners 2024). In contrast to conventional construction—where costs are incurred incrementally during the construction phase—factory production often requires developers to secure manufacturing capacity in advance, often through large deposits paid during the predevelopment stage to reserve a position in the production queue. This shift effectively moves a portion of construction financing earlier in the development process, creating a need for bridge financing that many projects struggle to secure. Innovative financing mechanisms have emerged to address this challenge. For example, Local Initiatives Support Corporation (LISC)'s Modular Housing Development Fund applies a replicable financing structure linked to standardized housing platforms across multiple projects, allowing capital to be deployed earlier in the development timeline (LISC 2023). Such models help align project financing with the production requirements of IC and facilitate factory-built housing to scale. Financing tools should be evaluated not only for whether they fill a capital gap, but whether they reward repeatability, verified performance, shorter cycle times, lower rework, and reduced delivery risk.

9. Demonstrate success and grow the evidence base. Private developers, municipalities, and the AEC industry are extremely risk averse and reluctant to deviate from established models without evidence demonstrating that promising alternatives are achievable in practice (Hawke et al. 2026). Regional pilot projects are a critical step in demonstrating innovative prototypes, as well as to establish a feedback loop to track and share key performance indicators, set benchmarks, identify what works and what doesn't, and share best practices across industry. Establishing a record of successful outcomes paired with project data, sustained across multiple regions, is needed to build public awareness and confidence in new models of housing production and to drive continuous improvement by industry. At a minimum, pilots should report total delivery cost, approval duration, factory labor hours per unit, site labor hours per unit, schedule duration, rework rate, inspection pass rate, operational energy use, embodied carbon, resident satisfaction, and maintenance issues during the first years of occupancy.

10. Grow the industry base and train the future workforce. Scaling IC to meet statewide production goals will require rapid and sustained growth in production capacity, the training of a skilled workforce and a reorganization of the current housing supply chain ecosystem. As noted, the RHNA (2023-2031 Cycle) mandates planning for over 2.5 million new homes, with at least 1 million designated for lower-income households. This translates to building over 350,000 units annually. A factory-area-per-unit-produced metric can be applied as a simple indicator of factory capacity. Southern California is home to a handful of factories producing modular housing. Factories range in size and report varying output capacities. Typical area/unit values range from approximately 200 sq ft/unit to 350 sq ft/unit with annual outputs ranging from 700 – 800 units. Assuming a typical factory produces 800 units/year and requires 140 full time employees, to get to 350,000 units/year would require 438 such factories (built instantaneously) staffed by a total of approximately 61,000 workers and capable of operating at sustained productivity levels. Or, alternatively, assuming gross factory floor area requirements of 350 sq ft/unit, producing 350,000 units/year leads to 122,500,000 sq ft of gross factory area or 2,812 acres. Gardena, CA, covers a total area of approximately 5.9 square miles, which is equivalent to roughly 3,776 acres. Therefore, a single factory campus meeting the entire housing production needs for California could be situated within a footprint ranging from 1/2 to 3/4 the land area of Gardena, depending on the space use efficiency of the factory model. Better integration of design, manufacturing, and supply chains has the potential to further accelerate the production of FBH. Planning and land use changes informed by site suitability and supported by economic development incentives and workforce training initiatives, can facilitate the creation of geographically concentrated industrial ecosystems, further reducing logistics, costs and time.

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AI-assisted Tools: Disclosures and Responsibility
AI-assisted tools used: ChatGPT, Google Gemini
Used for: AI tools were used for light editing, research and to locate and format references for some sources. AI tools were also used to edit and format bulleted lists into table format.
Extent: Light editing / research / organizing bullet lists into table format.
Human review: The authors reviewed and verified all content, calculations, and citations.