

Assessment of Embodied Carbon Impacts of Modular Construction for Housing: A California Case Study

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Overview

Background

- California needs to rapidly provide housing to meet demand while also mitigating embodied carbon emissions

Goal

- Present a modeling framework for assessing the embodied carbon of modular housing

Approach

- Estimate material take-offs and emissions of actual and prototypical projects
- Scale up to assess impacts of multifamily housing needs in each county

Funding

- California Air Resources Board

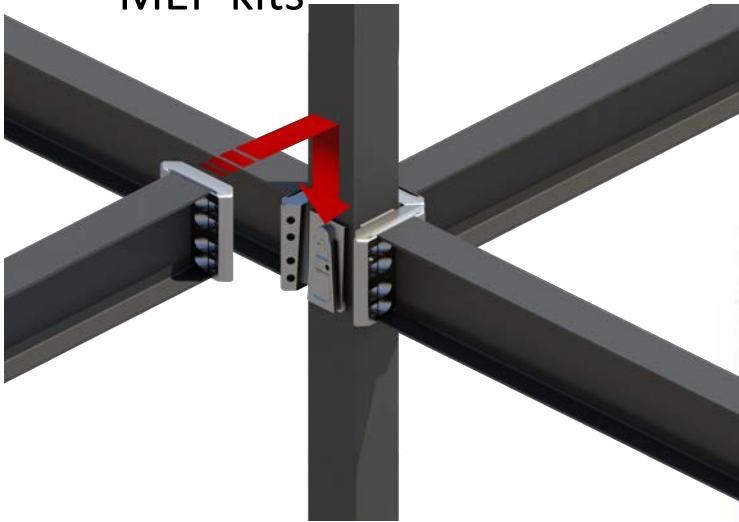


The Mayfair Station, Lowney Architecture. Source: ©Emily Hagopian

Industrialized Construction – Terminology

Prefabricated

- Prefabricated steel, timber framing
- Precast concrete
- MEP kits



<https://www.conxtech.com/conx-systems/>

Panelized

- Factory-built wall, floor, roof elements



<https://arpanel.eu/sandwich-panels/>

Modular

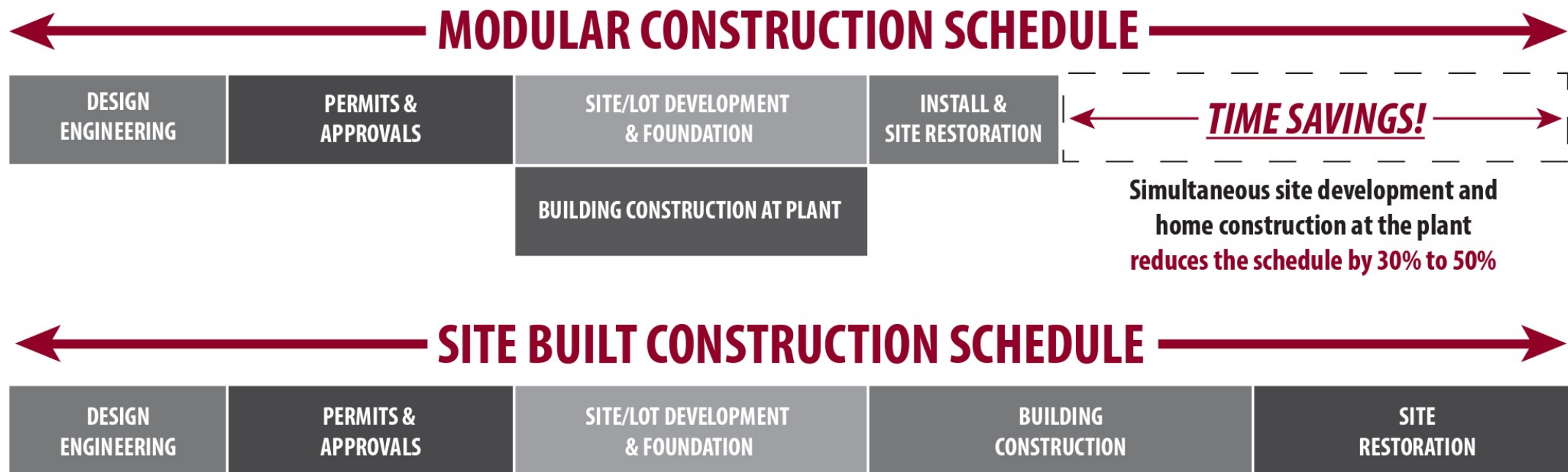
- Fully completed volumetric “pods”



Source: ©Emily Hagopian

More Background on Modular

- Just over 6% of new construction in 2022 (MBI Report, 2023)
- Multifamily sector accounts for one-third of factory output (MBI Report, 2023)



Source: <https://www.modular.org/industry-analysis/>

Modular Housing Projects in California

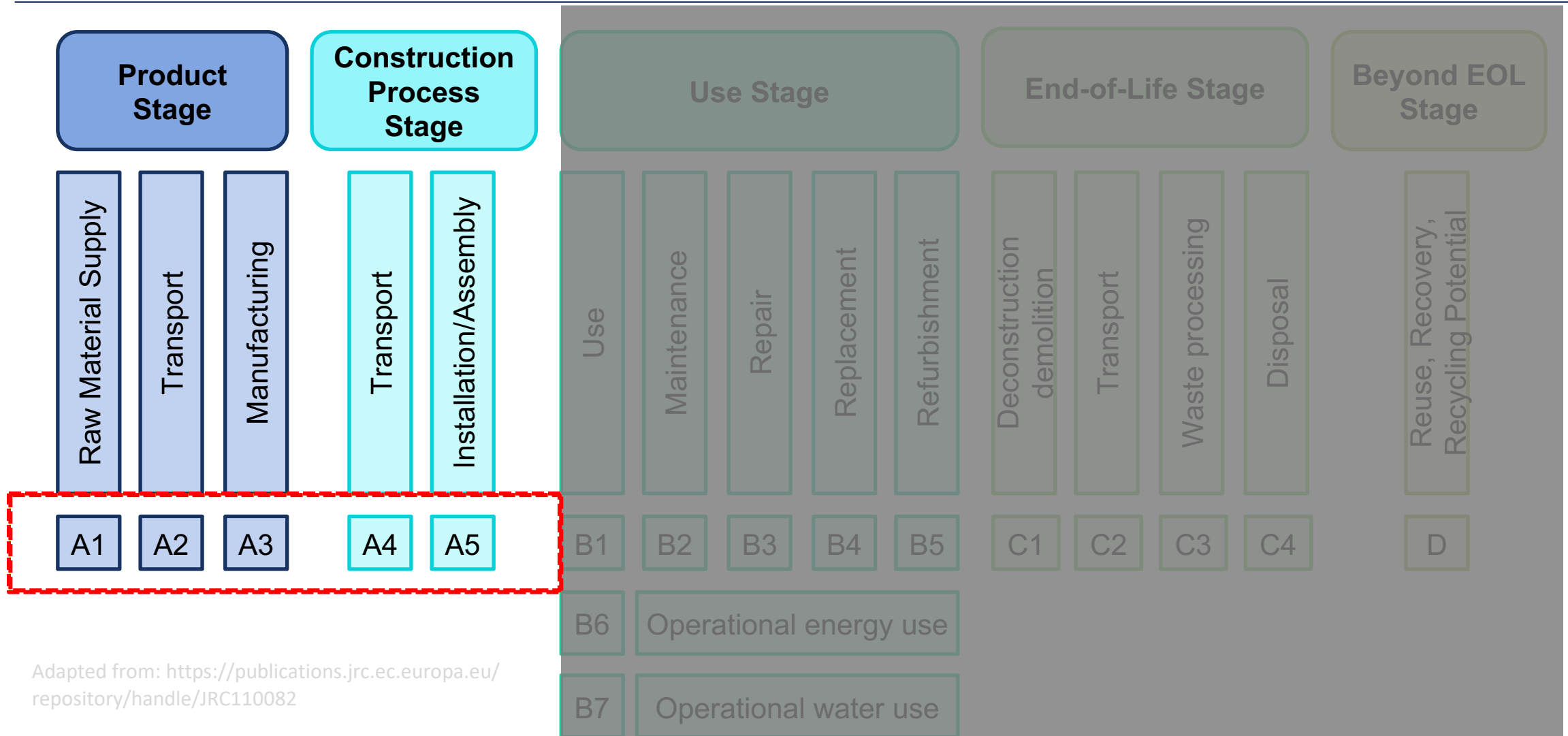


Source: <https://ktgy.com/4300-san-pablo-modular-construction-has-an-image-problem-housing-proponents-are-trying-to-fix-it/>

Source: <https://www.dbarchitect.com/work/modular>

Source: <https://alamedasun.com/news/city-awarded-123-million-build-dignity-village>

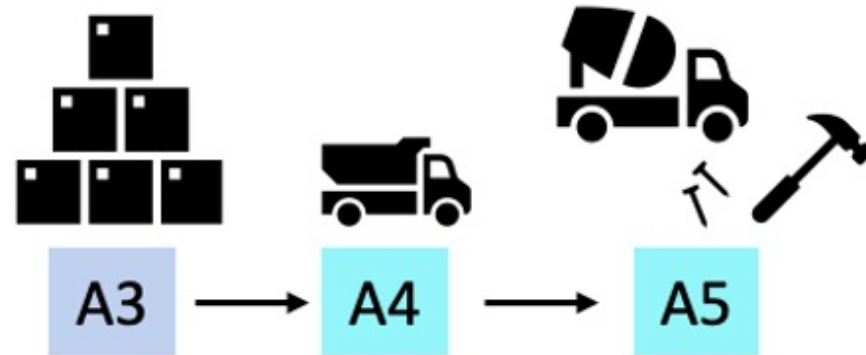
Whole-building life-cycle assessment



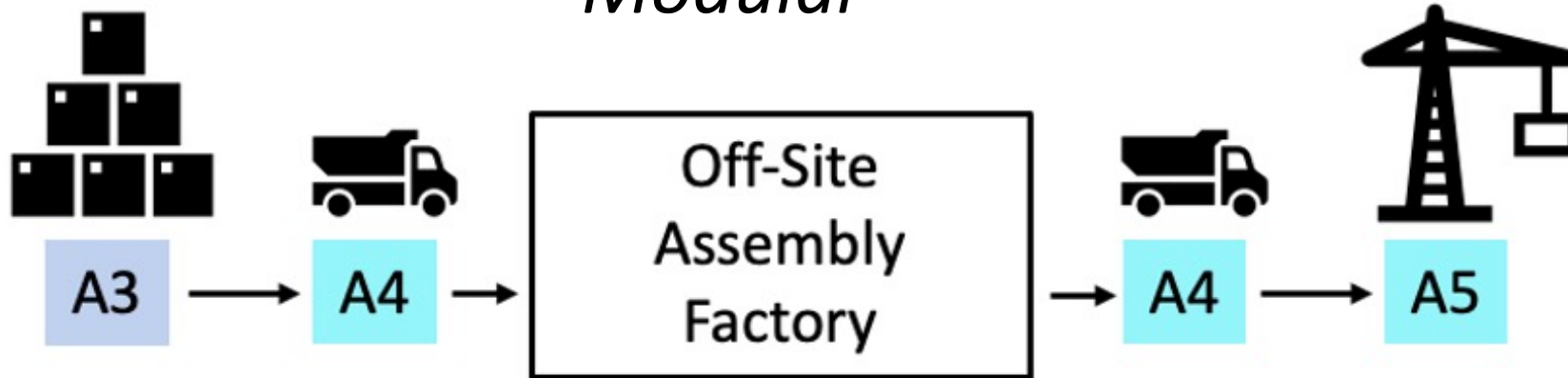
Adapted from: <https://publications.jrc.ec.europa.eu/repository/handle/JRC110082>

What is modular construction?

Traditional



Modular



Why pursue modular construction in California?

Potential Advantages*

- Time (and cost) savings
 - 10-30%
- Improved building value
 - Perception of higher quality control
- Lower environmental impacts
 - Reduction in waste
- Opportunity to leverage advanced manufacturing to spur productivity

California's Needs

- More than 2.5 million housing units need to be built in California by 2030
- GHG emission reduction targets under AB 32, AB 2446

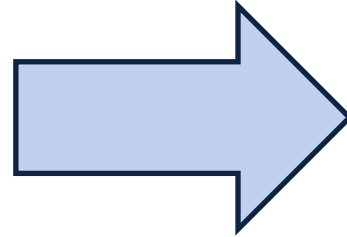
*See recent studies from UC Berkeley's Turner Center for Housing Innovation: <https://turnercenter.berkeley.edu/>

How should California assess the embodied carbon impacts from modular construction in multifamily housing?

What is needed to assess the environmental impacts of modular housing?

Prior Research*:

- Single building-to-building comparisons
- Default parameters for construction, transportation
- No California-specific case studies



Proposed Approach:

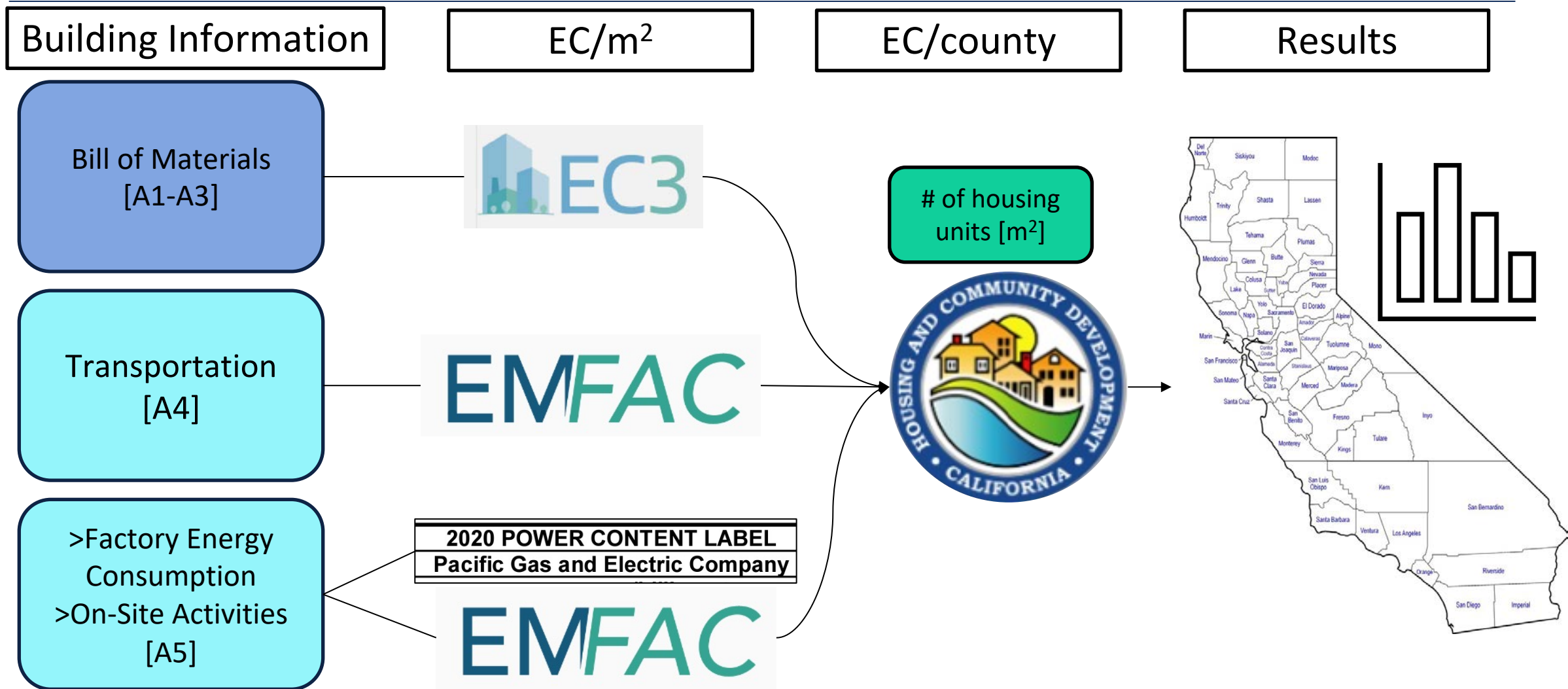
- Multiple modular typologies
- Scale up from single building to number of housing units needed in each county
- Assess different combinations for each county

*Publication under review: "Modular construction's capacity to reduce embodied carbon emissions in California's housing sector"

Methods: Building Typologies

Type	Frame	Story	Approx. Gross Area (m ²)	BOM Data
Traditional	Timber	3	3,700	Representative
	Timber	2	2,800	Representative
	Steel	5	4,500	Representative
Modular	Steel Shipping Container	2	700	Actual
	Timber	3	3,700	Representative
	Steel	4-6	37,000	Actual

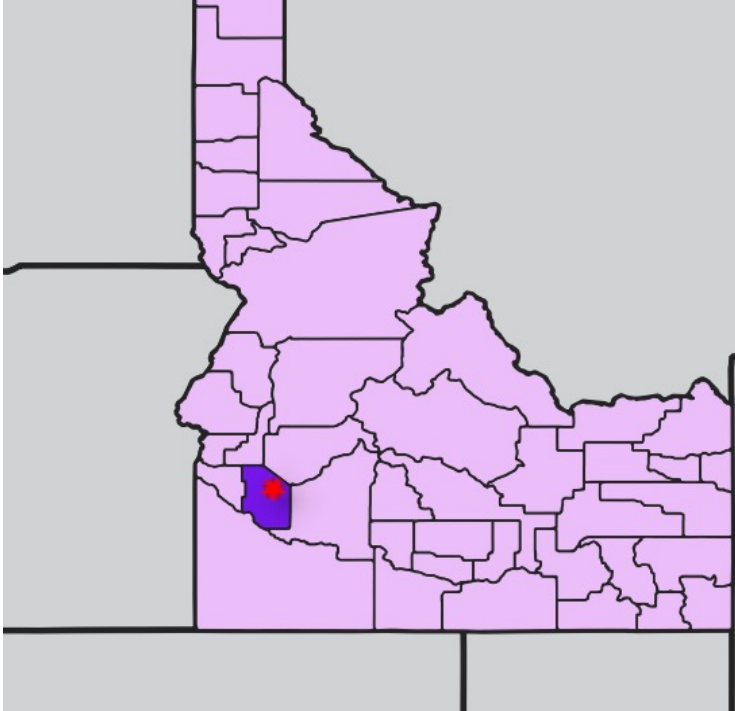
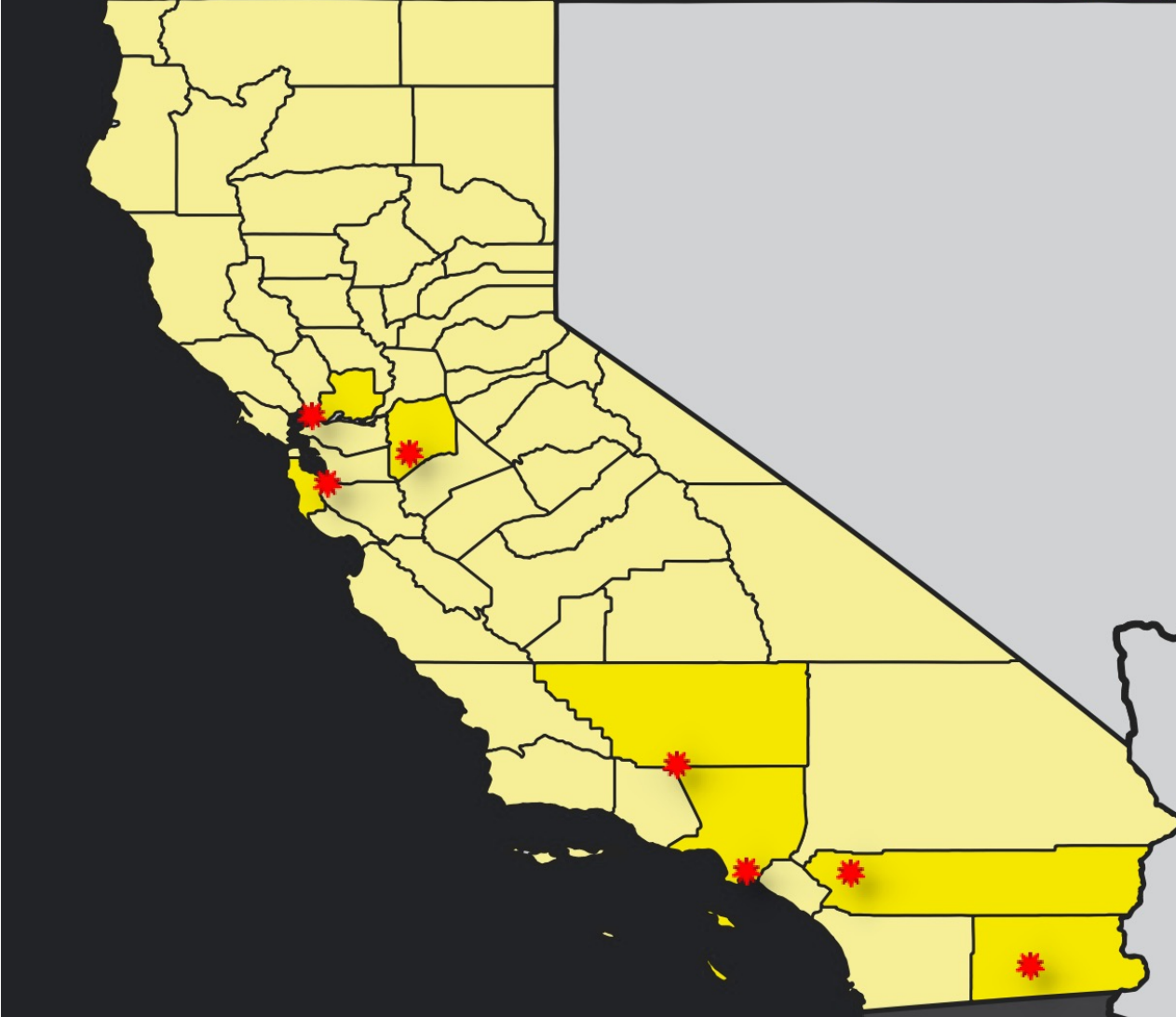
Methods: Embodied Carbon from Modular Housing



Methods: Emissions Scope - Comparing to Traditional Construction

Housing Type	Bill of Materials	Transportation	Construction
Factory-Built/Modular	Standard foundations Floor Construction Ceiling Finishes Exterior Windows Wall Finishes Floor Finishes Interior Walls/Partitions Exterior Walls Roof Construction Roof Coverings	Upstream + Delivery of modules to housing site	Factory manufacturing On-site assembly of modules
Traditional	Same as modular	Upstream	On-site construction

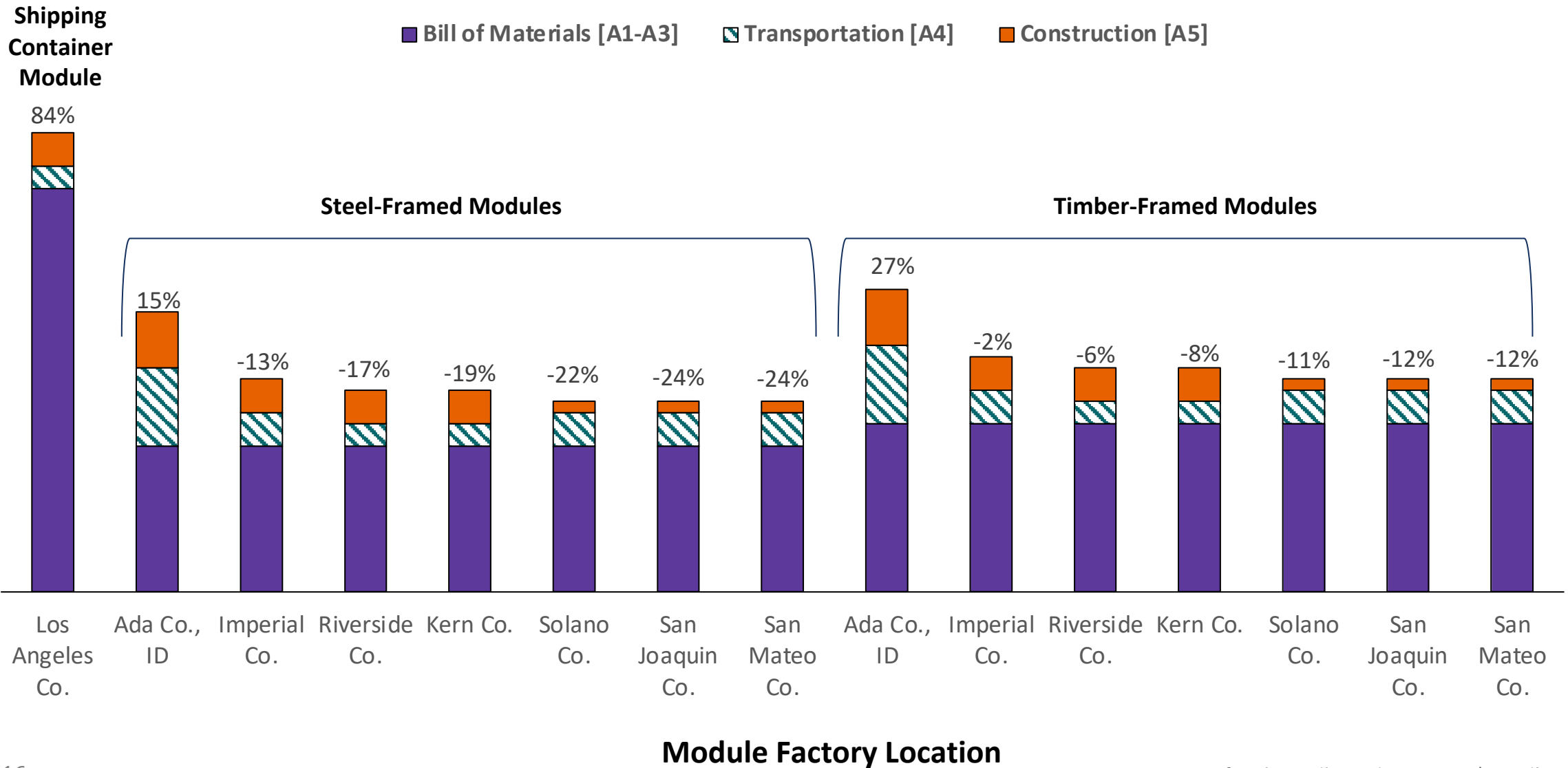
Methods: Factory Locations



Will modular construction help
California reduce embodied
carbon emissions in the housing
sector ?

Results: Comparing all modular types statewide to on-site, timber-framed

% Δ in EC Emissions Relative to On-Site, Timber-Framed



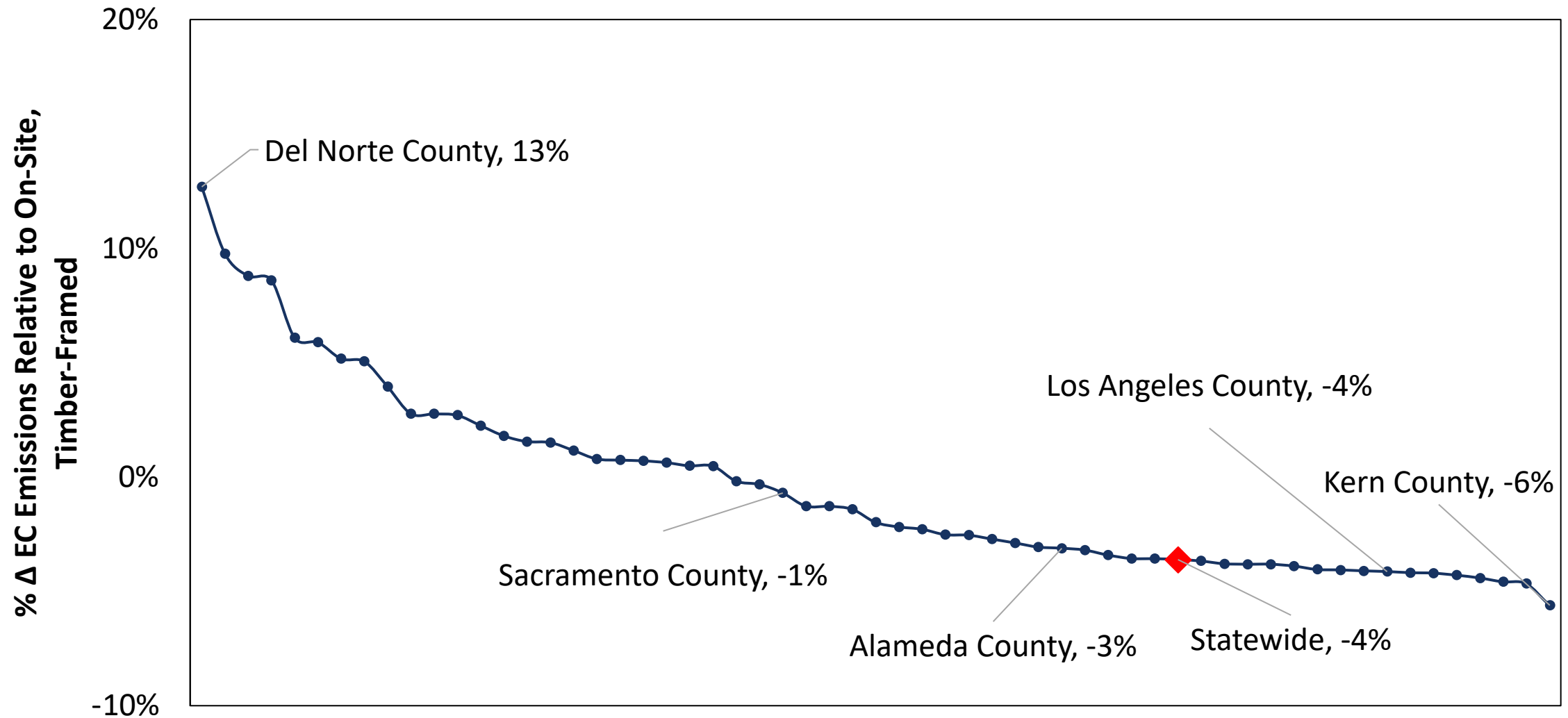
Results: Sensitivity Analysis on Los Angeles County

Modeling Variable	Δ from Baseline Value of Variable	Δ in EC Relative to On-Site, Timber-Framed, On-Site
Module floor area	↓ 100%	↑ 450%
Delivery flatbed truck capacity	↓ 100%	↑ 300%
BOM emissions intensity – modular types	↓ 100%	↑ 130%
BOM emissions intensity – traditional types	↑ 250%	↑ 200%

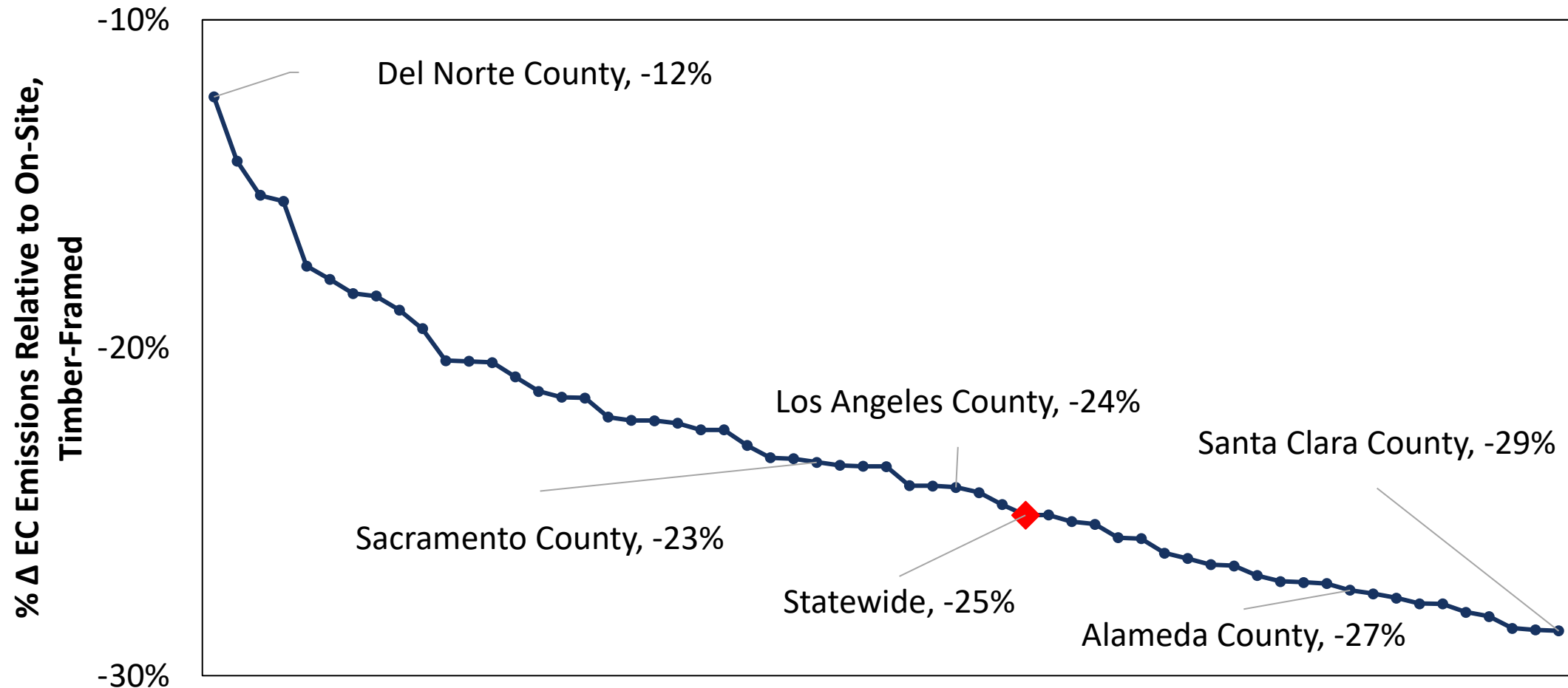
- On-site construction emission factor
- Crane lifting time
- Factory electricity consumption
- Factory electricity emission factor

} Not as impactful on EC emissions

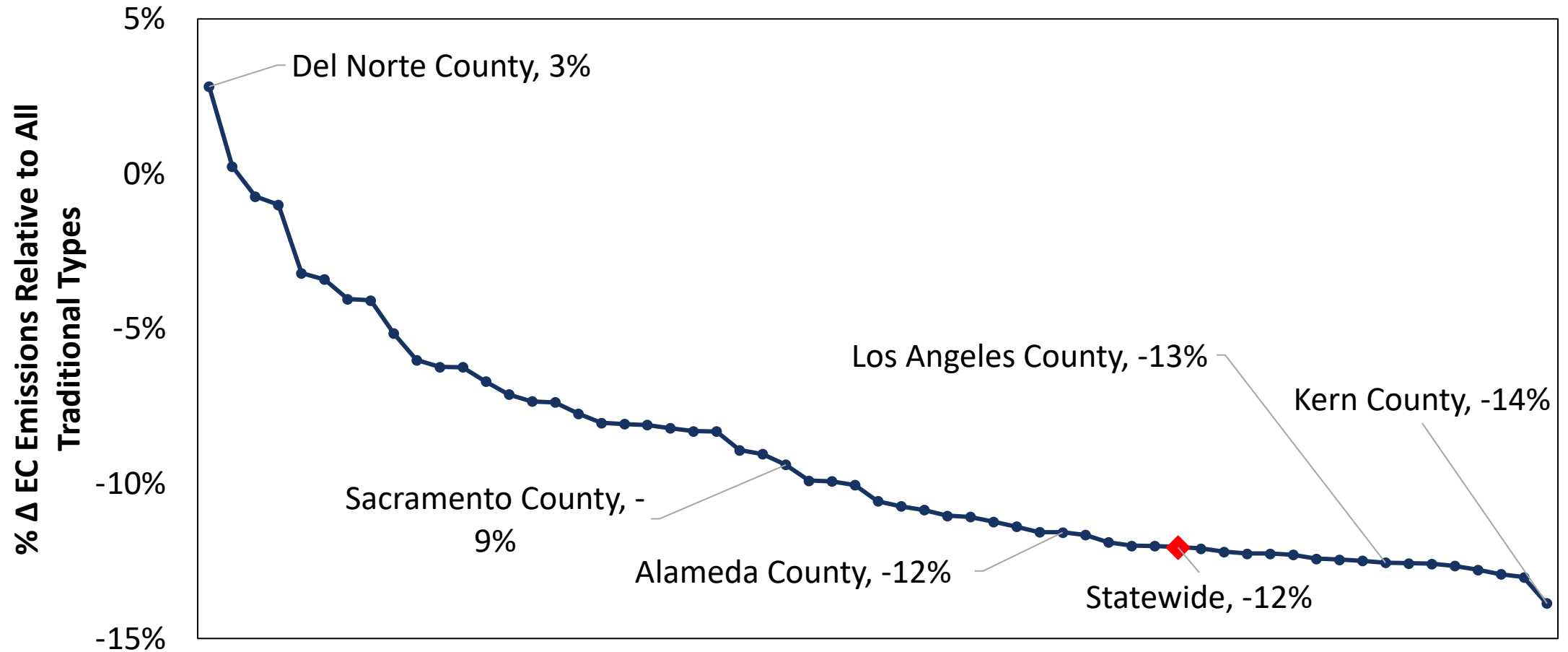
Results: Monte Carlo analysis – randomized (n = 15,000) allocation of modular types compared to on-site, timber-framed by county



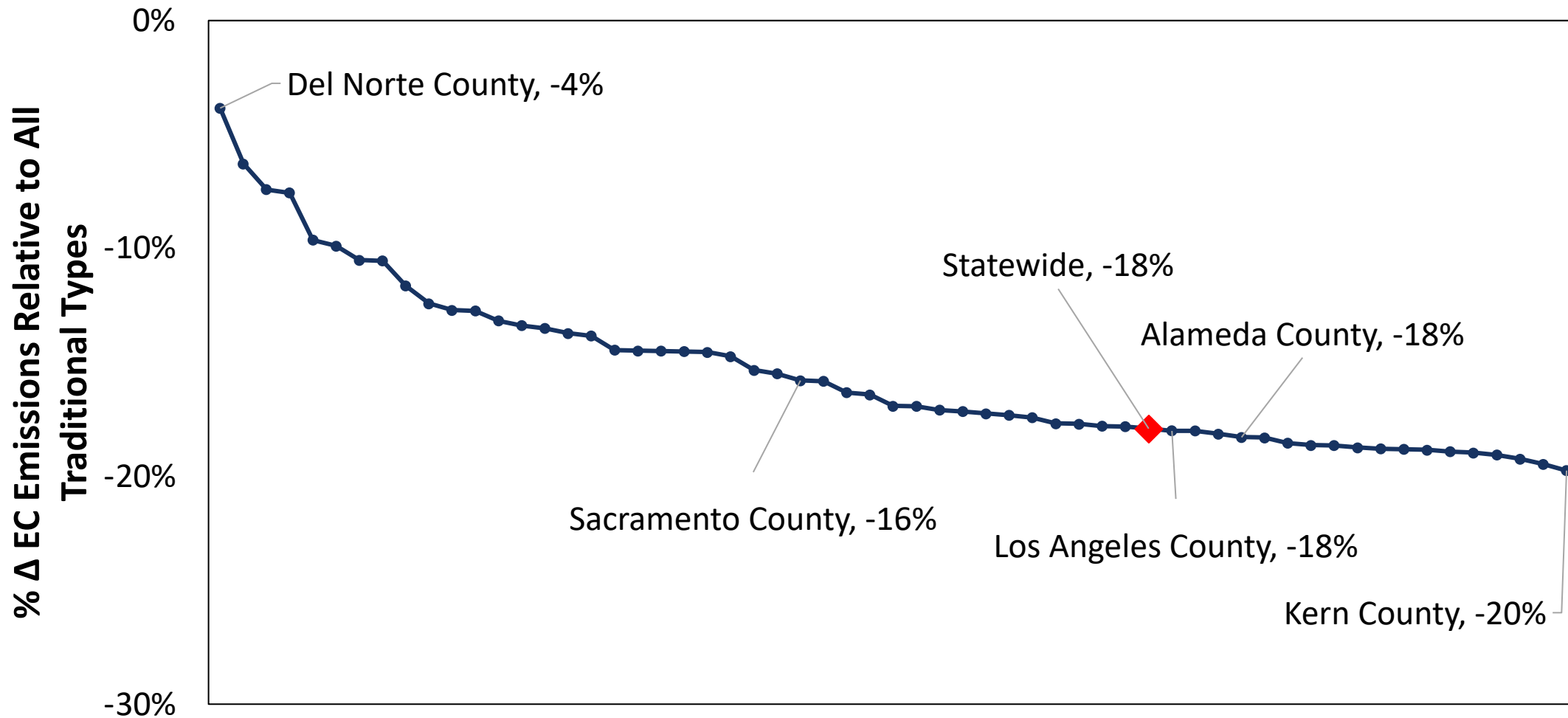
Results: Monte Carlo analysis – randomized (n = 15,000) allocation of modular types (except shipping container) compared to on-site, timber-framed by county



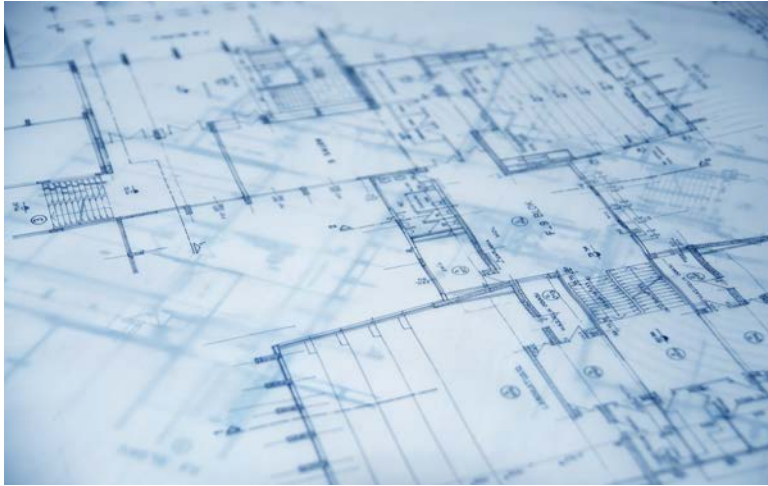
Results: Randomized allocation of modular types (except shipping container) compared to randomized allocation of traditional types by county



Results: Randomized allocation of modular types (except shipping container) compared to randomized allocation of traditional types by county



Opportunities to improve analysis (Limitations)



- Add more real-world building examples from existing and future projects

- Increase number of realistic modeling parameters (e.g., framing systems, WASTE, factory locations, module components)

- Expand scope to include key life cycle stages (operational, EoL)
- Build upon work by NREL

Modular Factory: <https://www.sfchronicle.com/bayarea/article/modular-homes-san-francisco-17463783.php>

NREL:
<https://www.nrel.gov/buildings/industrialized-construction.html>.

Is modular the most EC-efficient strategy to achieve needed housing?

Modular Capacity

- Mismatch between near-term factory capacities (~5,000-10,000 units/year) and housing need (2.5 million units by 2030)

Adaptive Reuse

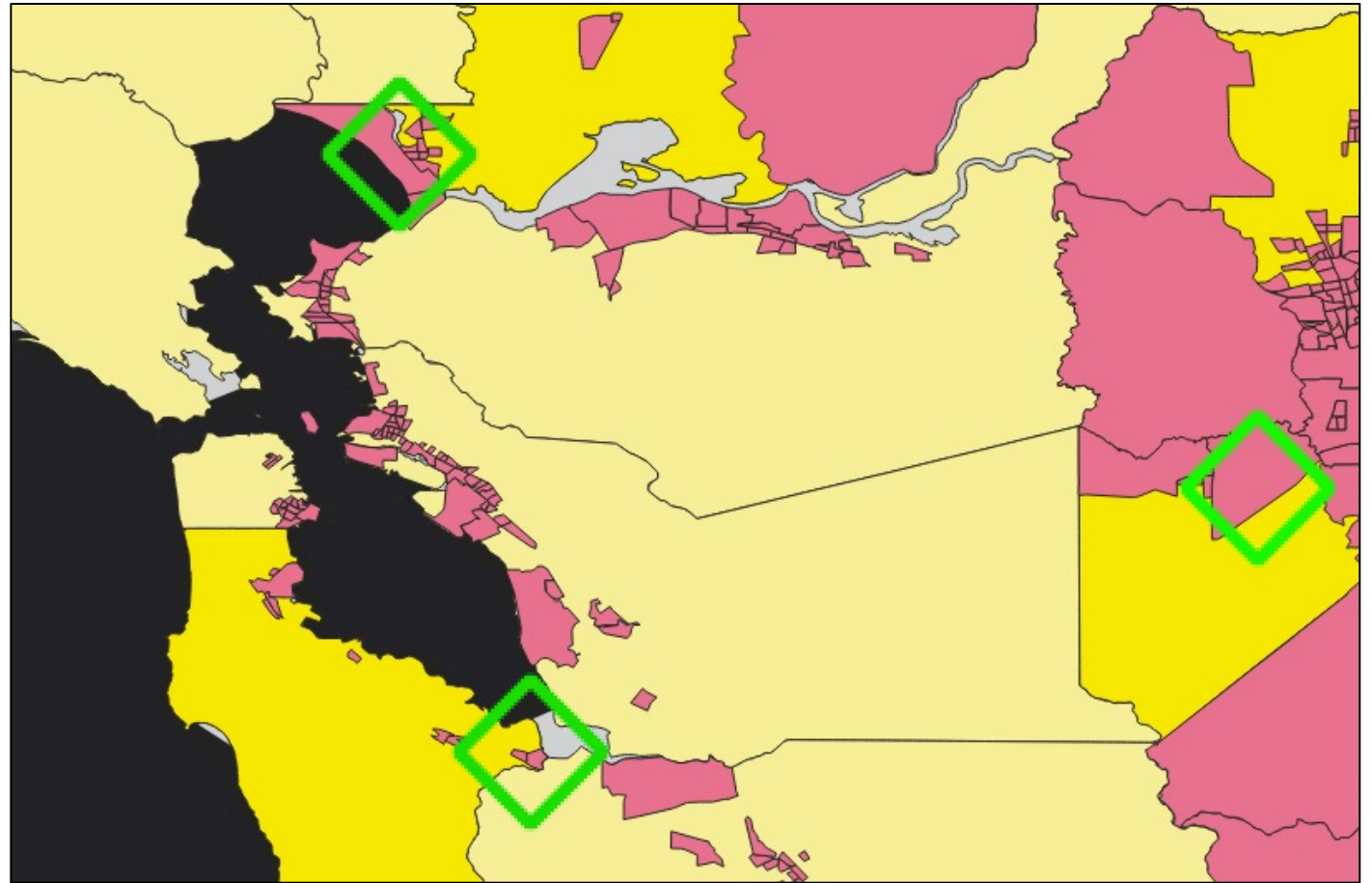
- Recent work shows repurposing existing non-residential buildings in California can achieve 35-50% in EC savings (Gursel et al. 2023)



Applying systems thinking to modular construction to consider additional concerns

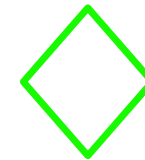
Environmental Justice:

- Many of the current factories (green diamonds) are in SB 350 Disadvantaged Communities (pink census tracts)
- What would be the impact of increased production?



SF Bay Area Factories.

Modular Factories:



SB 350 DAC:



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