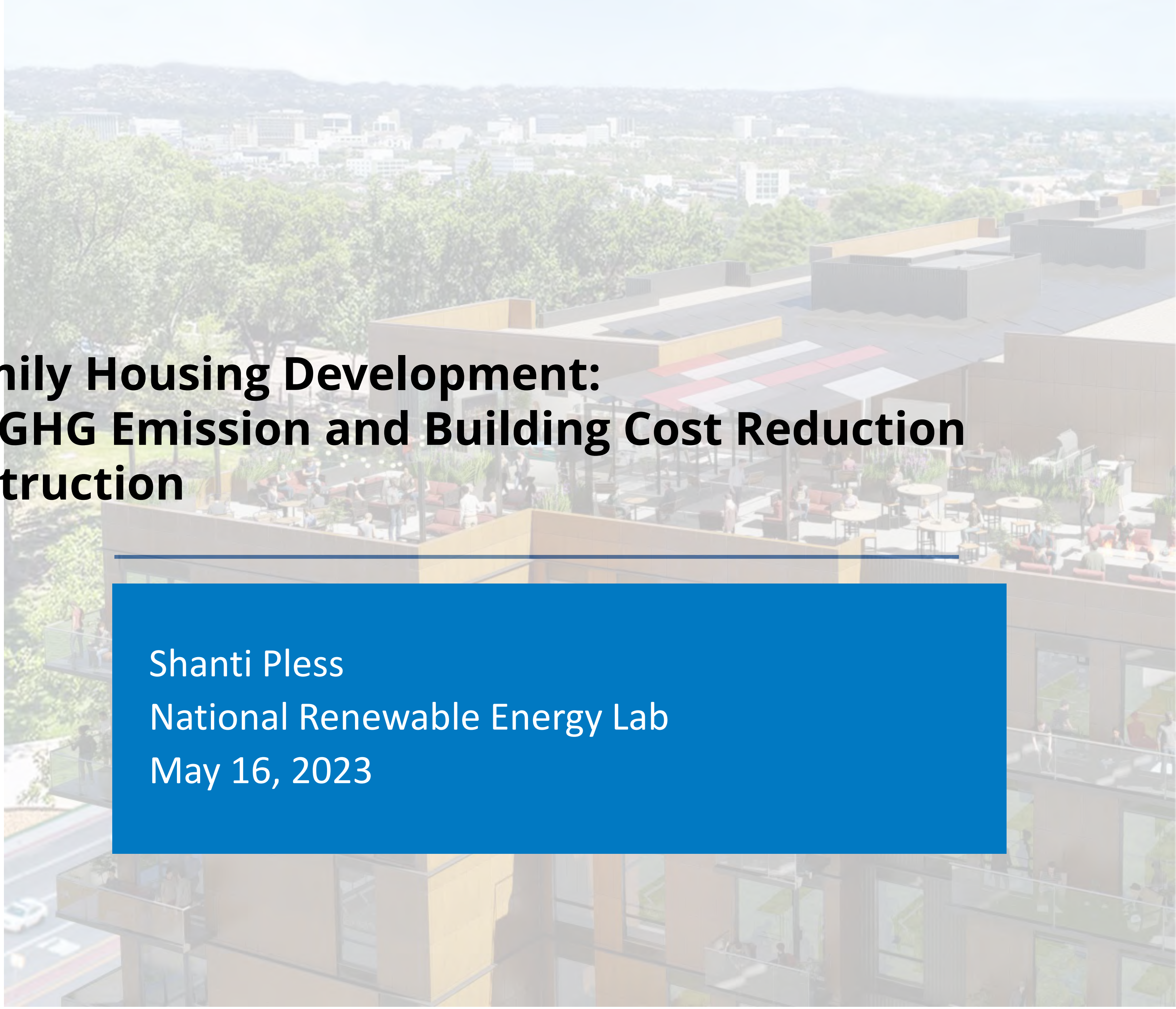
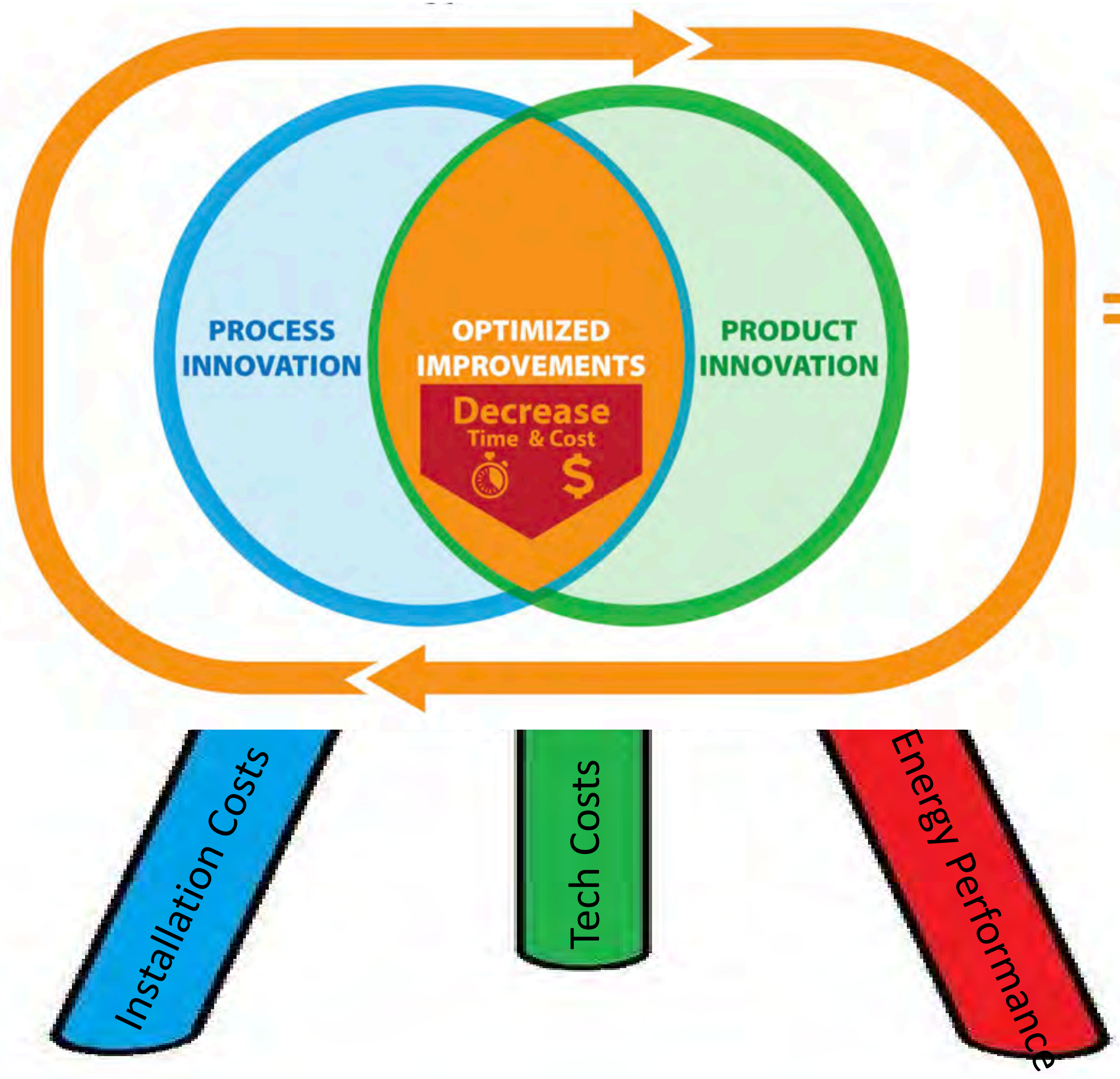
Decarbonizing Multi-Family Housing Development: Actionable Pathways to GHG Emission and Building Cost Reduction with Industrialized Construction



Shanti Pless
National Renewable Energy Lab
May 16, 2023

Innovate on Process to Install EE



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Better Product
Affordable, net-zero energy, low-carbon, and healthier

&

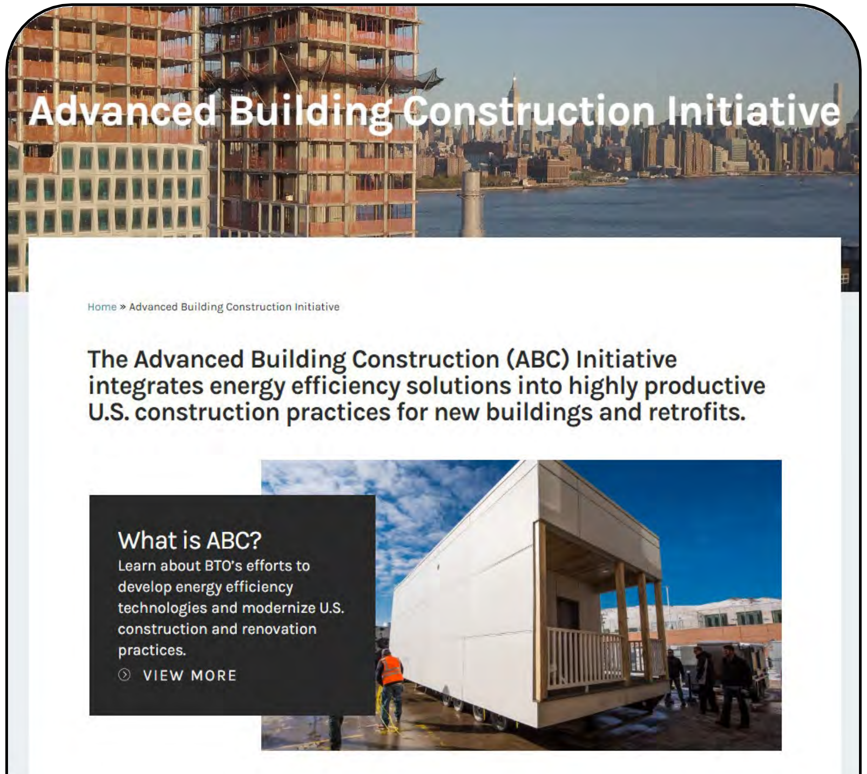
Better Process
Improving productivity, quality, carbon emissions, and affordability of building construction

U.S. DOE "Advanced Building Construction"

Net-Zero Energy| Low-Carbon | Affordable | Appealing

Mission:

- Help deliver affordable, appealing, high-performance, low-carbon new buildings and retrofits at scale
- Help integrate energy efficiency solutions into highly productive U.S. construction practices for new buildings and retrofits



Source: ABC Initiative webpage

Advanced Building Construction (ABC) offers a powerful solution.

In short, ABC refers to retrofit and new construction approaches that combine:

Energy-efficient decarbonization

+

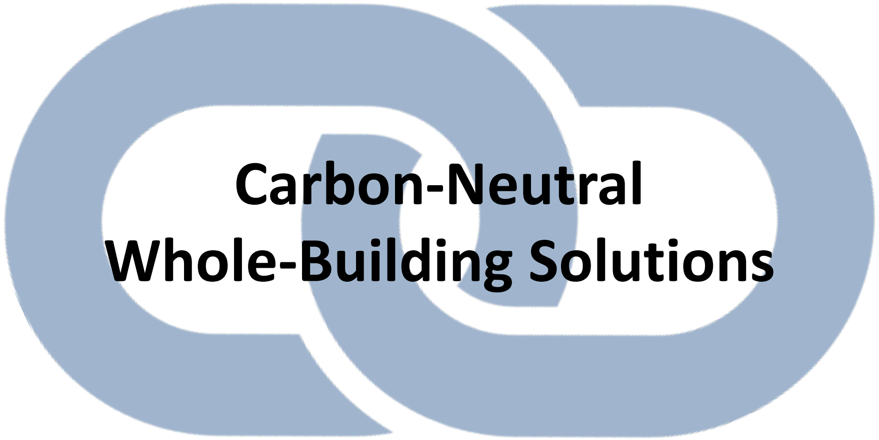
Scalable, streamlined industrialized construction

ABC: Industrializing Construction to Decarbonize Buildings

DOE's Advanced Building Construction (ABC) Initiative is focused on **accelerating the decarbonization of the U.S. buildings sector** through **industrialized construction** innovations that deliver **efficient, affordable, and appealing new buildings and retrofits at scale**.

Development & Demonstration

Innovate & validate appealing solutions that can achieve carbon neutrality for common and high-impact building types.



Market Transformation

Use the ABC Collaborative to communicate consumer interests and inform product design; aggregate demand; reduce risks; and establish competitive business models.

ABC Initiative Investments Focus on Technologies, Manufacturing, & Markets

www.buildings.energy.gov/abc

Zero Energy Mixed Use and Multifamily: Site Built Examples

Boulder Commons

http://bouldercommons.com/
https://crej.com/news/boulder-commons-to-add-more-office-plus-apartments/

UC Davis Student Housing at Net Zero

https://www.ucdavis.edu/news/west-village-expansion-start-construction
https://www.ucdavis.edu/news/zero-net-energy

Zero Energy Mixed Use and Multifamily: Site Built Energy Strategies

- Near Passive House levels of insulation
  - Enhanced air tightness
- Triple pane windows
  - Electrochromic, automated shades
- Mechanical ventilation with heat recovery
- 100% LEDs
- Electric heating and hot water
  - Heat pump hot water heating
  - VRF, Air Source, Ground Source Heat Pumps
- High efficiency appliances
- Technology, tenant monitoring, and control integration
  - Smart home technology
- Unit level façade and rooftop PV
  - Battery storage and grid coordinated controls

But all struggle with cost effectiveness and affordability…

Revive Properties:
https://revivefc.com/features/#energy-benefits

"America's construction industry productivity is lower today than it was in 1968."

The report calls for a global effort to modernize and upgrade the construction industry across seven broad areas:

- Reshape regulation and raise transparency
- Rewire the contractual framework
- Rethink design and engineering processes
- Improve procurement and supply-chain management
- Improve on-site execution
- Infuse digital technology, new materials, and advanced automation
- Reskill the workforce

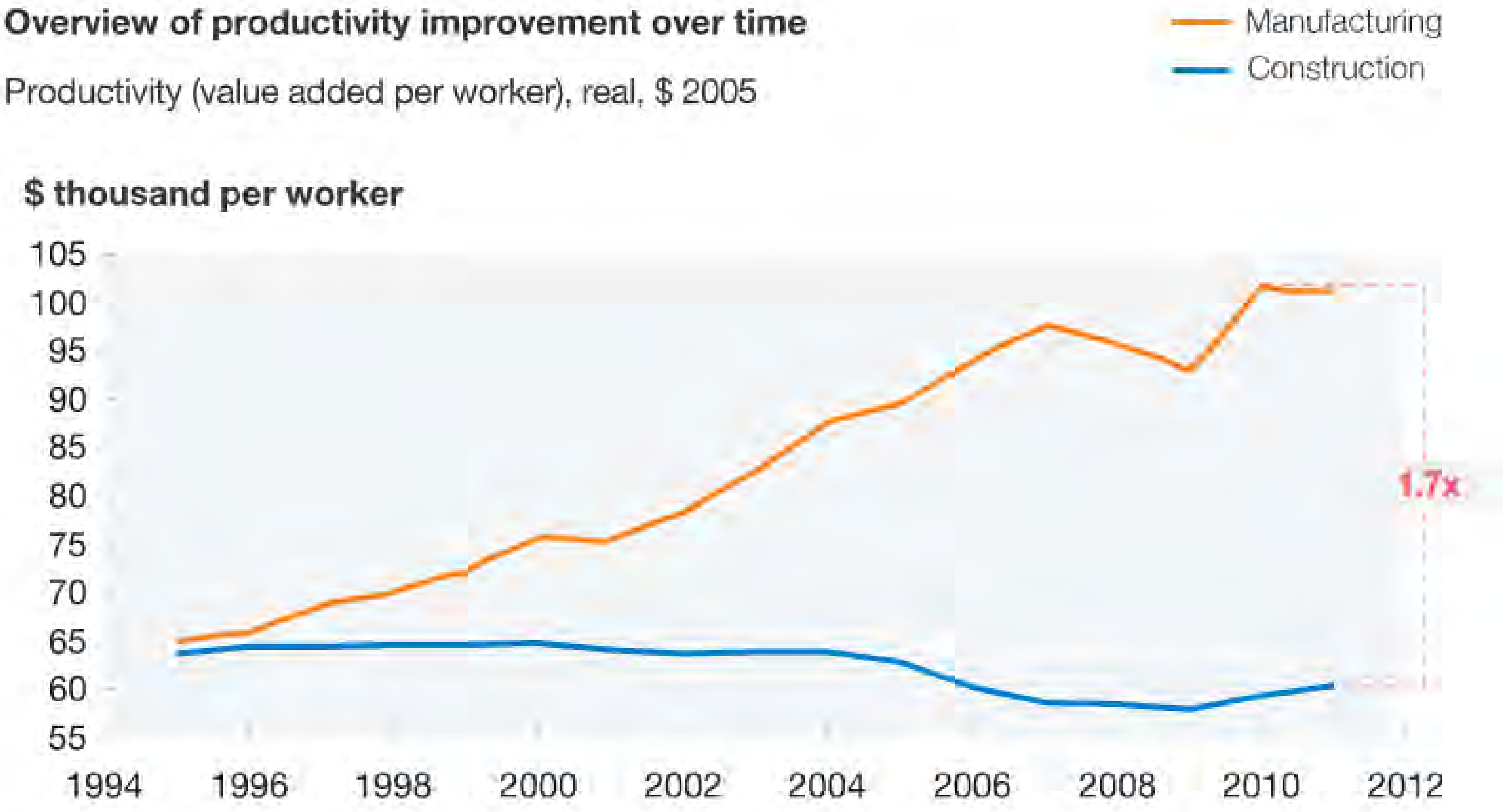
"Parts of the industry could move toward a manufacturing-inspired mass-production system, in which the bulk of a construction project is built from prefabricated standardized components off-site in a factory. Adoption of this approach has been limited thus far, although it's increasing. Examples of firms that are moving in this direction suggest that a productivity boost of five to ten times is possible."

http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution

Productivity in manufacturing has nearly doubled, whereas in construction it has remained flat.

Overview of productivity improvement over time

Productivity (value added per worker), real, $ 2005



Source: Expert interviews; IHS Global Insight (Belgium, France, Germany, Italy, Spain, United Kingdom, United States); World Input-Output Database

McKinsey&Company

TERNER CENTER FOR HOUSING INNOVATION
UC BERKELEY

SEARCH

ABOUT THE CENTER

WHO WE ARE

BUILDING AFFORDABILITY BY BUILDING AFFORDABLY: THE CASE FOR OFF-SITE MULTIFAMILY CONSTRUCTION

POSTED ON MARCH 07, 2017 BY CAROL GALANTE AND SARA DRAPER-ZIVETZ
FILED UNDER: INCREASING THE SUPPLY OF HOUSING,

To remain relevant and successful over time, every industry must modernize and adapt to changing demand ... nt industry is no except ... ons and revolutions in bu ... s face rapidly changin ... advances, and an eve ... y be timelier than ever.

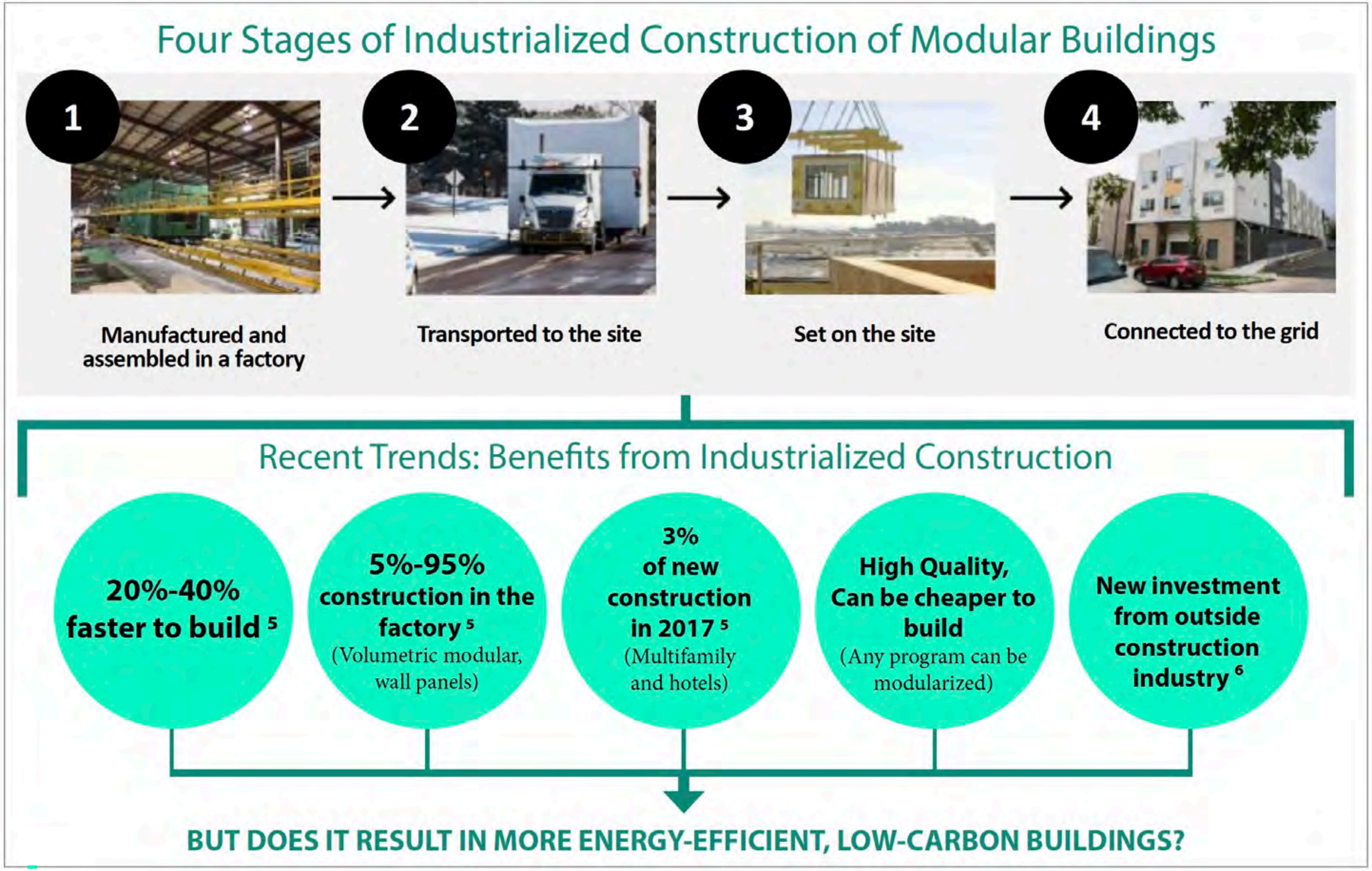
How will the housing ... port from McKinsey & Co ... better said, overdue, ... construction have ha ... in increasingly costly d ... production of housir ... o produce it demands ... the cost of construction ... are certainly a major factor.

"Off-site construction of housing, which leverages the efficiencies of factory production to achieve significant cost savings, represents a much needed solution to this problem. It has the potential to revolutionize the way homes and apartments are built."

"Inefficiencies in traditional construction have hampered productivity and driven costs up for decades, resulting in increasingly costly development. Today, in many regions in the United States, the production of housing - especially infill multifamily housing – has become so costly to produce it demands rents or sale prices that are unaffordable for most people."

http://ternercenter.berkeley.edu/uploads/offsite_construction.pdf

Industrialized Construction



Permanent Modular Construction Partners in Multi-family

Primary Building Material: Wood

Primary Building Material: Steel

Volumetric Building Companies—Hamlet, North Carolina

Blokable — Vancouver Washington

Factory_OS—Vallejo, California

FullStack Modular—Brooklyn, New York

Partner with leading factories and showcase projects to achieve optimal integration of energy systems within the emerging advanced manufacturing industry for buildings

MOMENTUM INNOVATION GROUP

Oregon State University
Civil and Construction Engineering

"How can optimal integration of a wide range of energy efficiency strategies in industrialized construction be achieved with little or no additional cost, labor, or production time?"

This question was addressed by NREL's ICI Team along with project partners as part of the 3-year DOE funded project "Energy Efficiency in Permanent Modular Construction (EEPMC)."

Design for Manufacturing and Assembly for Energy Efficiency Strategies

- Factory installed EE strategies can simplify installation, better control scope and scheduling, enhance quality, standardize means and methods, increase construction productivity, and reduce overall construction timelines
- Quantify trade-offs for strategies that increase cost of module but reduce construction cost/time/complexity and/or eliminate on-site scope

This allows modular solutions to maximize cost effectiveness of EE solutions and leverage industrial engineering and advanced manufacturing approaches to increase productivity and reduce first cost of construction

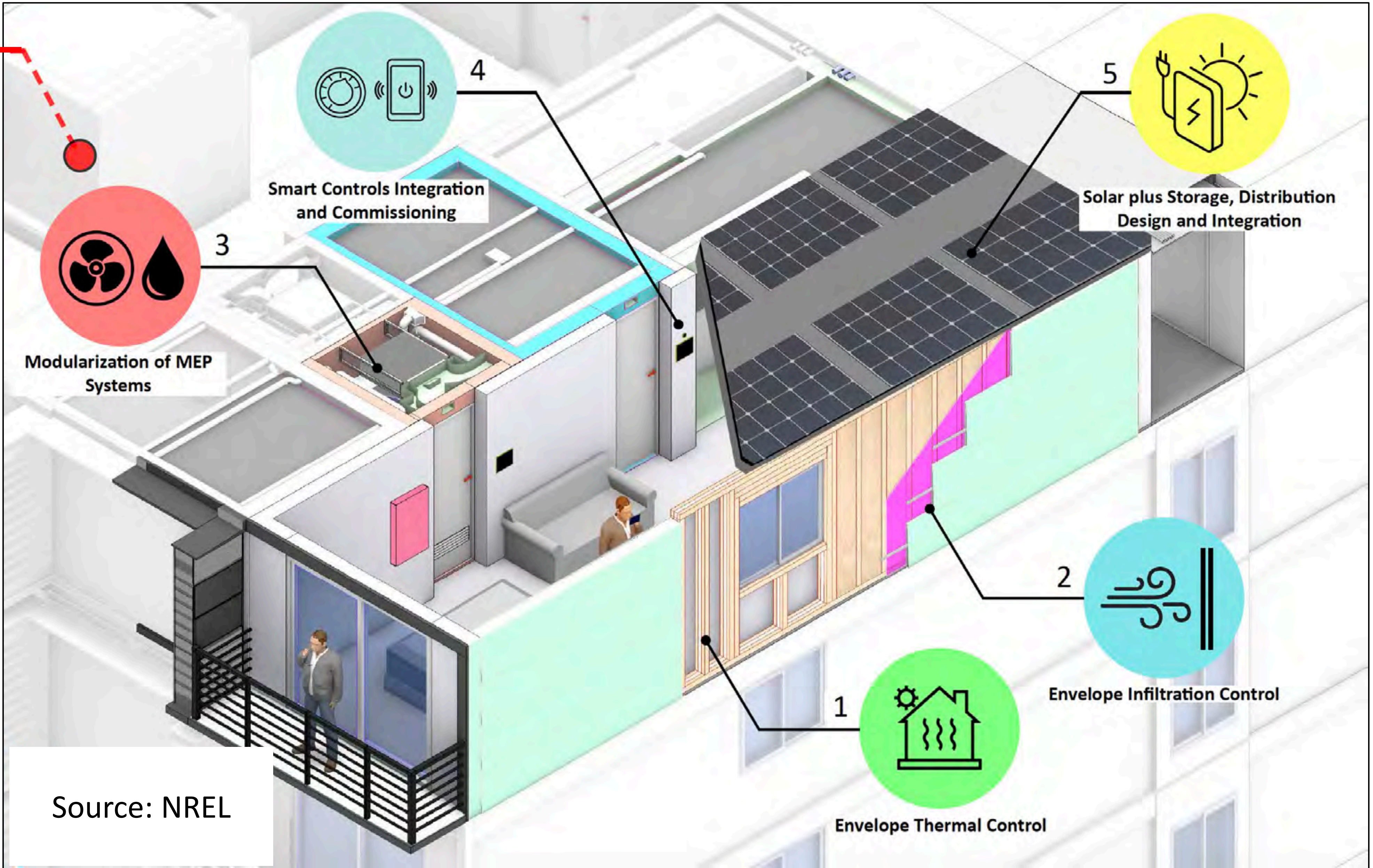
Zero Energy Modular?

Selected Energy Efficiency Strategies

1. Envelope Thermal Control
2. Envelope Infiltration Control
3. Modularization of MEP Systems
4. Smart Controls Integration and Commissioning
5. Solar plus Storage, Distribution Design and Integration

Whole-Building Design with unit-level EE integration

Ideal NZE, low-carbon modular housing unit



Source: NREL

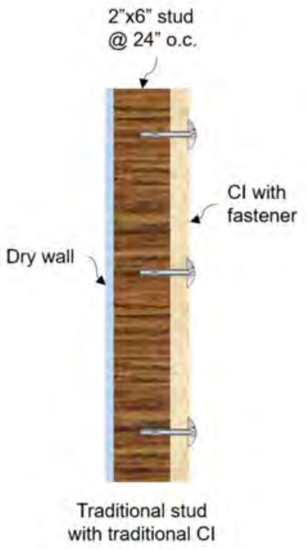
EE Strategy 1: Envelope Thermal Control

Key Takeaways:

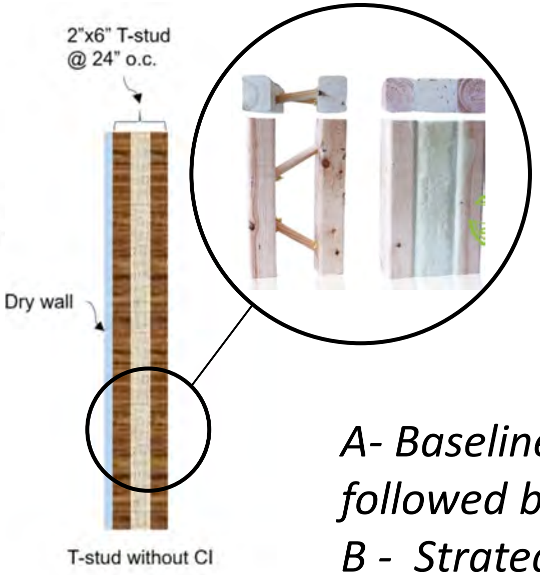
To optimally integrate the energy efficiency strategy of advanced thermal envelope, **we propose that a superior quality insulation system is installed in the factory, as opposed to on-site insulation systems. Towards this end, it is critical to design an EMOD-optimized factory-installed envelope system that also achieves similar thermal performance as on-site continuous exterior systems.**

- **Insulated studs**
- **SIPs**
- **Exterior insulation installed in factory with simple module to module detailing planned**

EE Strategy 1: Case Study



[A]



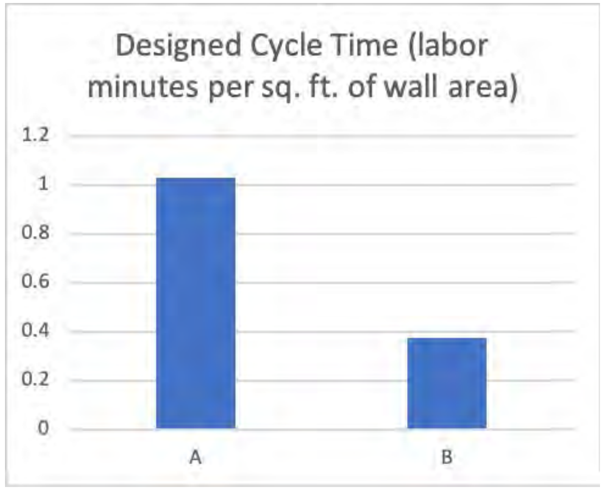
[B]

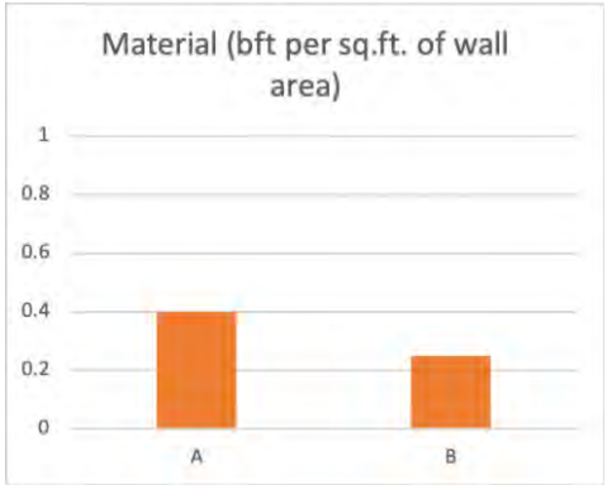
Benefits from Off-site wall framing with Insulated Truss Studs (ITSs) [B]:

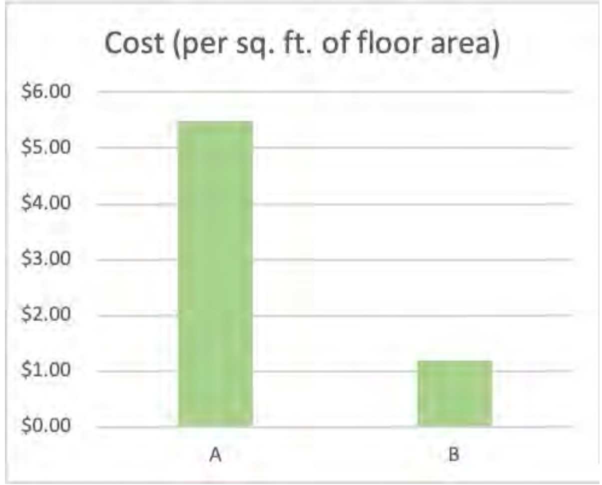
- Reduced labor-minutes by **63%**
- Reduced total material used by **38%**
- Reduced cost (material + labor) by **78%**

A- Baseline: Off-Site Wall framing with standard 2x6 studs followed by on-site continuous insulation

*B - Strategy: Off-Site Wall framing with ITSs and **no** on-site continuous insulation*







EE Strategy 2: Envelope Infiltration Control

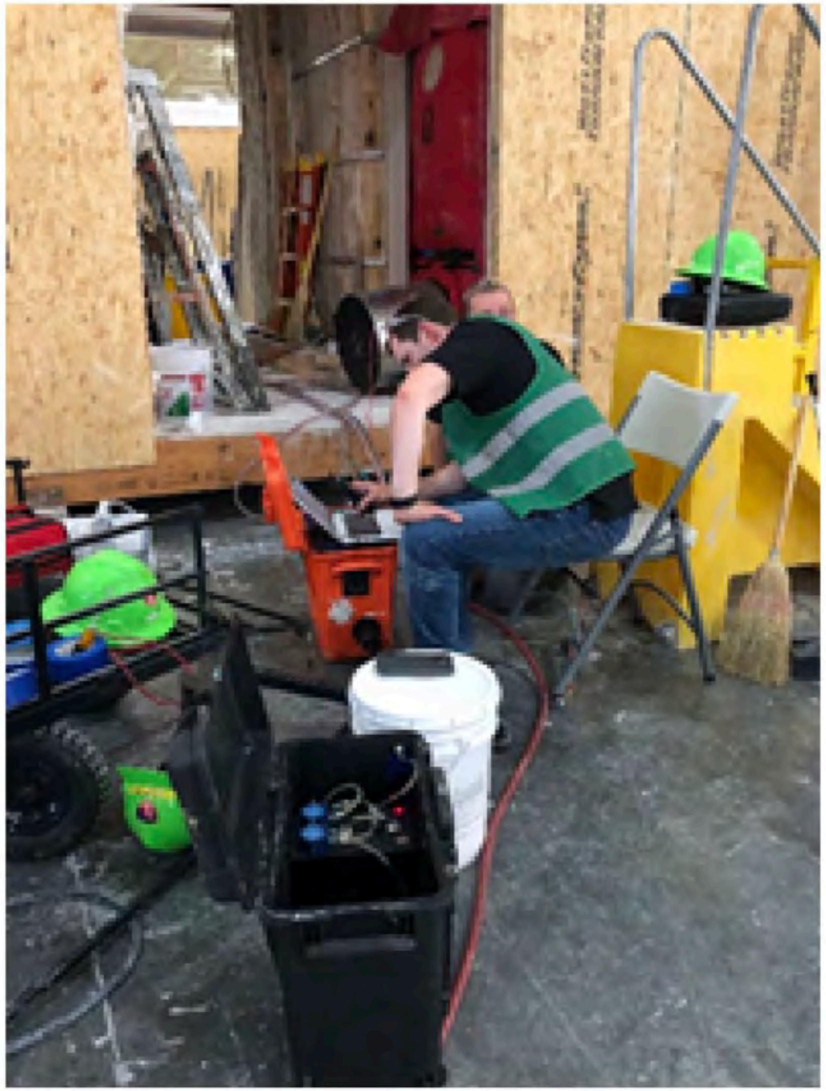
Key Takeaways:

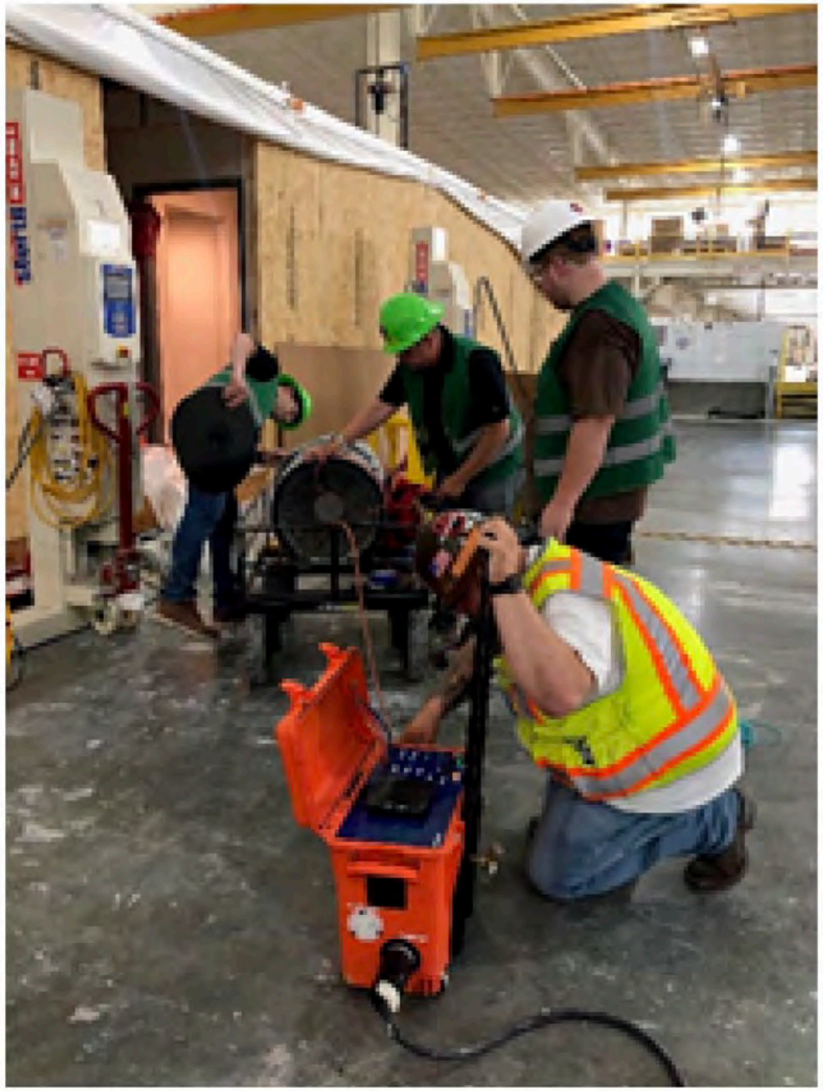
An example of in-factory airtightness improvement strategies includes the efficient use of ionized sealing. Lessons learnt from ionized sealing pilots could be leveraged to also identify opportunities for in-factory taping and caulking. We propose the following key steps to integrate the energy efficiency strategy of improved airtightness in the factory:

Use construction and manufacturing QA/QC tools and methods (such as non-destructive testing) to achieve factory-installed airtight envelope. The key steps involved are:

- Plan for a QA/QC design review of the envelope
- Test the airtightness on a set of modular units in the factory to evaluate air-barrier installation quality and develop specific strategies to ensure all modules adopt well-known standardized air-barrier details
- Test the airtightness on a representative sample of modular units at end of the factory production line to verify the airtightness value and the installation processes.

EE Strategy 2: AeroBarrier pilots at VBC factory





Still Need for Testing, Detailing, and Final Verification…

The key lessons learned are that **airtightness starts with design and material selection, and ionized sealing should be used for fine-tuning, with additional focus on set processes, final site installed details, and final testing.**

Based on the testing data prototyping and visual factory walkthrough of the station's activities and processes, **there is much room to impact the overall quality of modular units positively.**

Test #	Starting ACH	Ending ACH	% Reduction	Sealing time
Test 1	9.0	1.8	78%	56 min
Test 2	5.9	1.0	87%	41 min
Test 3	10.7	3.1	65%	40 min
Test 4	6.9	1.8	77%	30 min
Test 5	5.7	1.7	70%	48 min
Test 6	7.4	2.4	66%	23 min
Test 7	6.4	1.1	88%	45 min
Average	7.4	1.8	76%	40 min

EE Strategy 3: Energy Exchange Pod

Can we imitate the bathroom pod approach for mechanical system?

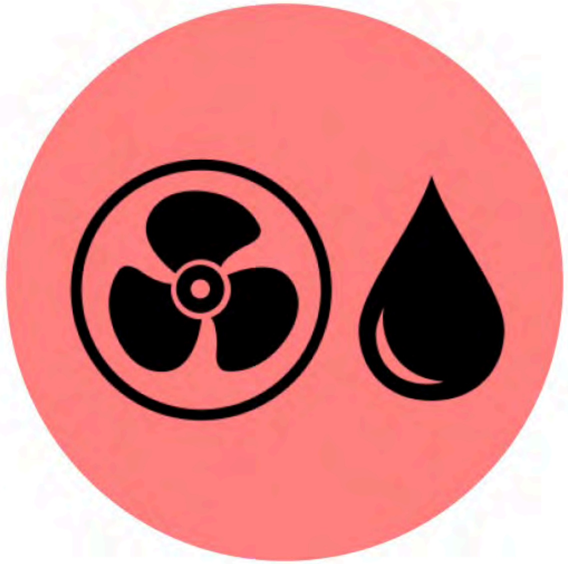
Common for bathroom pods to be:

- Prefabricated
- installed on-site or on volumetric modular factory line

‘Utility cupboards’ in the UK

- Prefabricated 540 ‘utility cupboards’ by Skanska UK for Battersea Project
- Took 18 man-hours to build vs 42 hours for those constructed on-site
- **44% cheaper, including factory overheads; 73% fewer defects**

EE Strategy 3: Energy Exchange Pod



Key Takeaways:

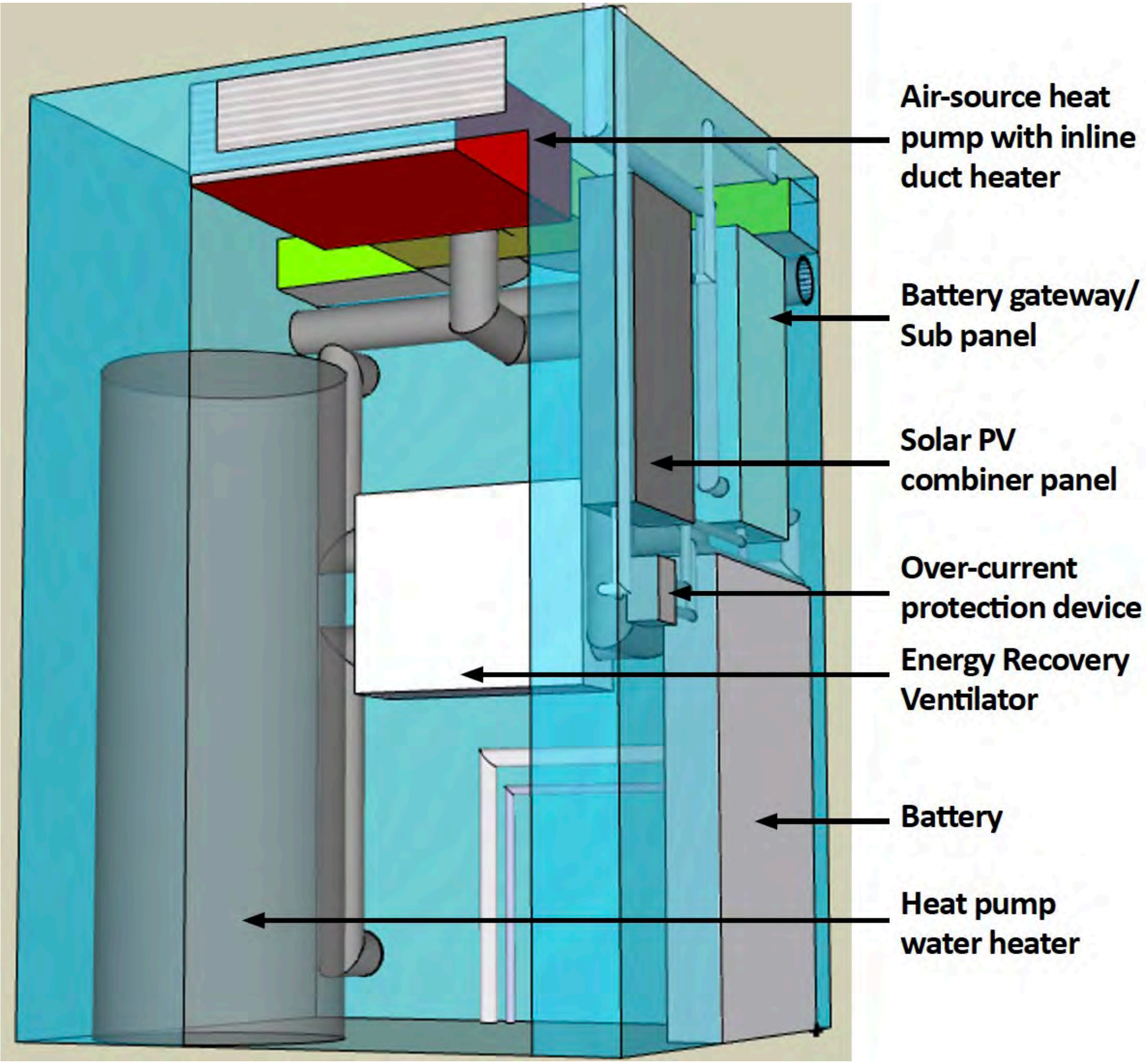
A unitized Energy Exchange Pod enables:

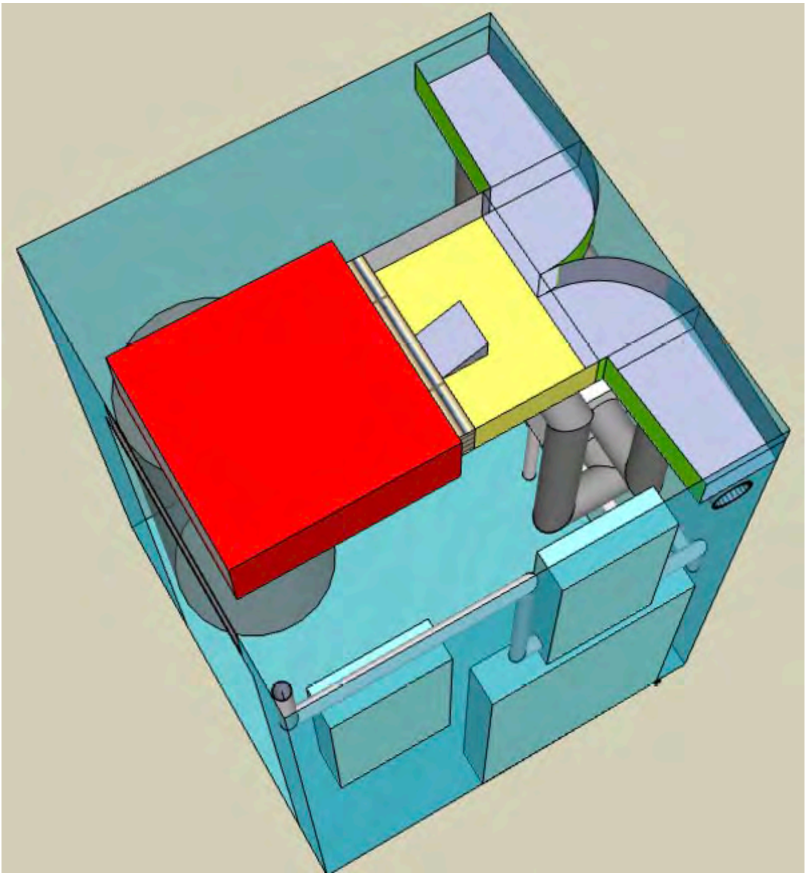
1. **Build -to-Stock of subsystems through chunking and prefabrication for volume production in production lines**
2. A unitized air system for each apartment.

By following the proposed methodology, the subassembly "pod" design (fully-implemented or partially-implemented) leads to the following benefits:

1. **Ensures proper ventilation that is hard to ensure with central ventilation systems and variable pressure across the height of a building**
2. **Limits unit to unit air cross contamination, reducing odor and acoustic pollution.**

EE Strategy 3: Energy Exchange Pod



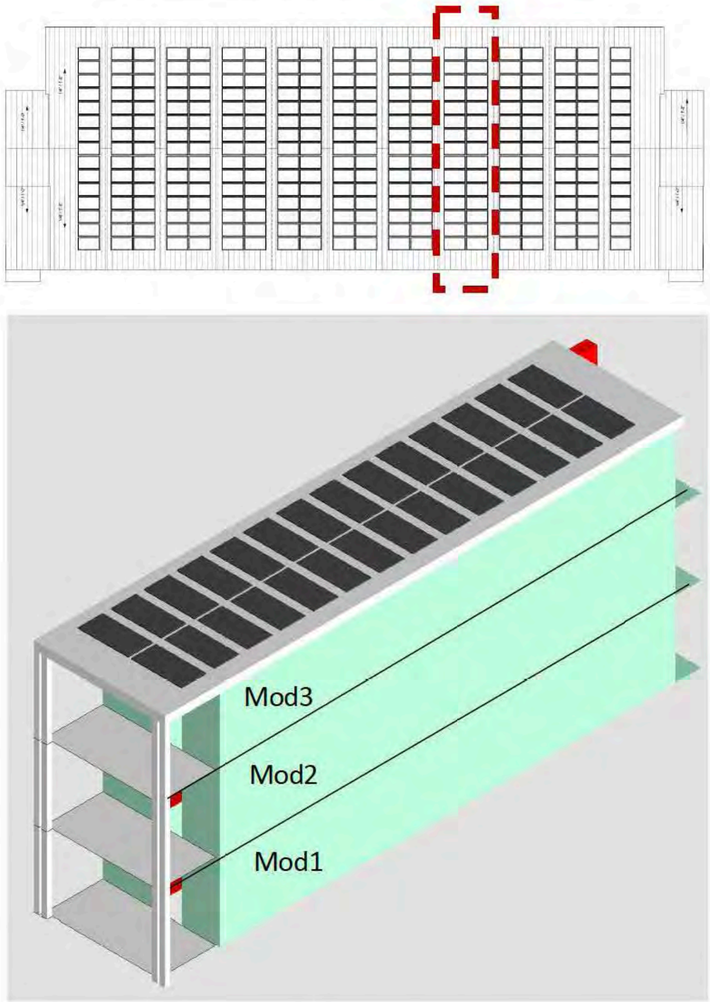


Source: VEIC

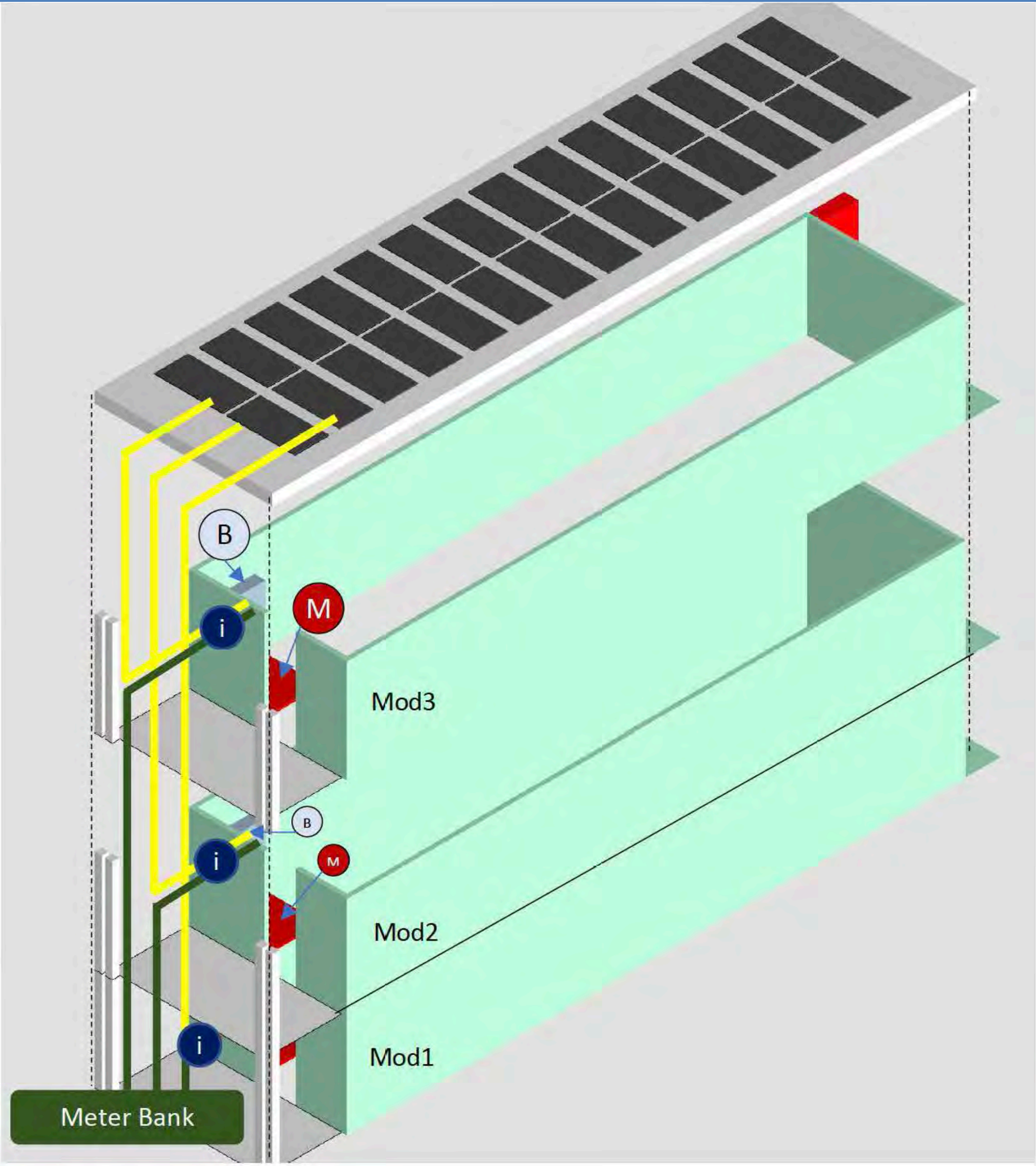
Solar Home Factory

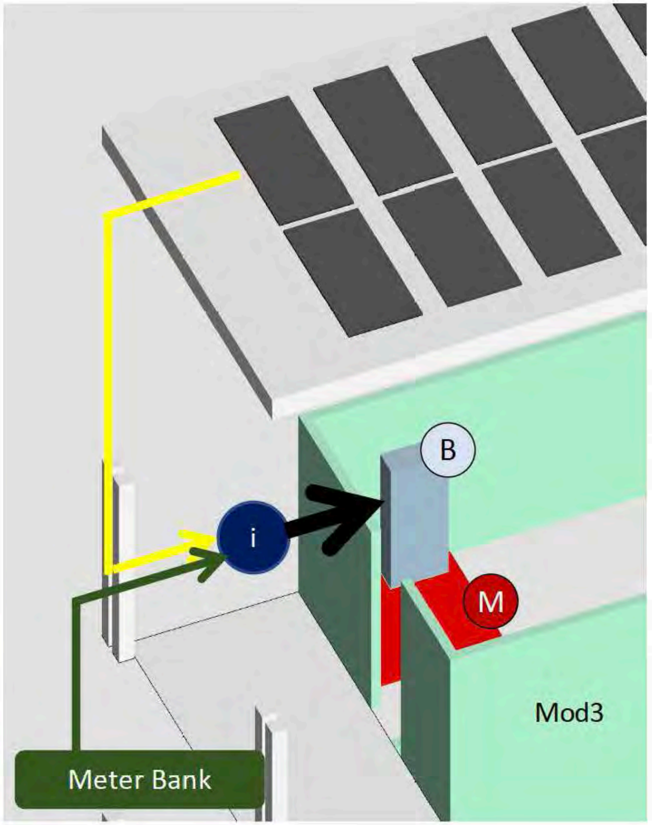
Modular Factory Installed Solar reduces install costs

EE Strategy 5: Solar plus Storage



Each Modular Tower with 3 modules (each LVL) and rooftop PV array





B Battery

M Mech Pod footprint

i Inverter

ENERGY IN MODULAR METHOD
[EMOD METHOD]

NREL
Transforming ENERGY

A GUIDE TO DESIGN FOR ENERGY EFFICIENCY
IN INDUSTRIALIZED CONSTRUCTION OF MODULAR BUILDINGS

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Momentum Innovation Group

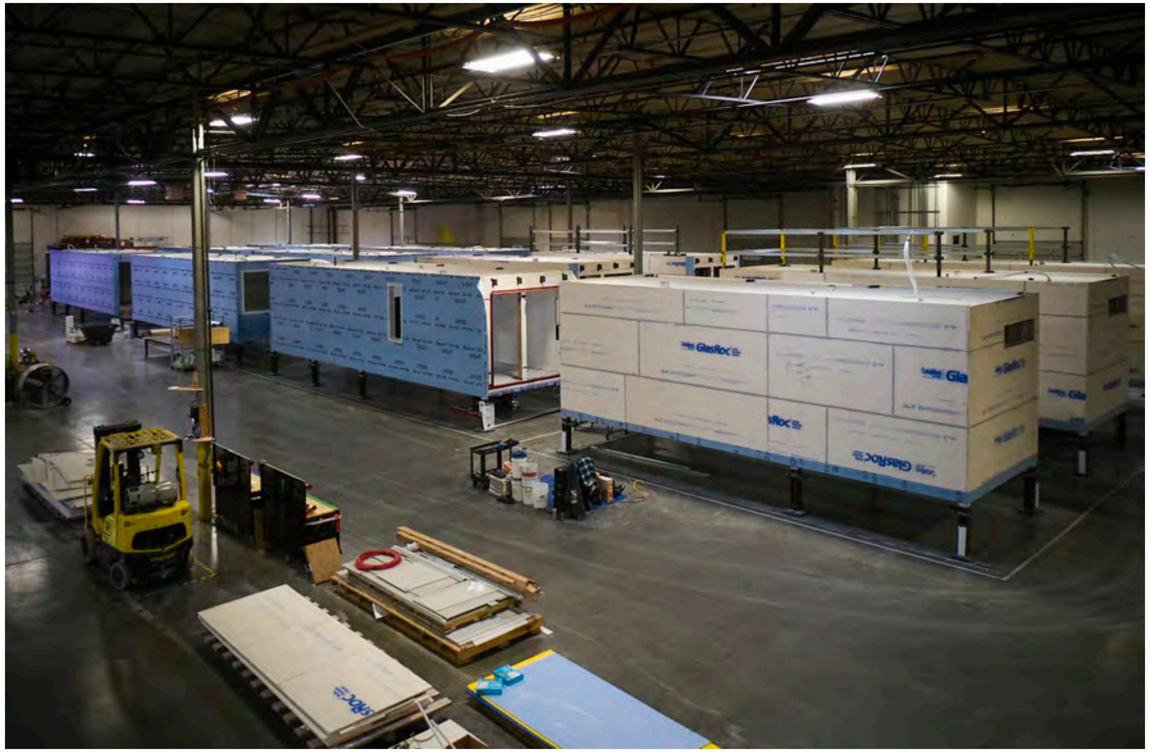
Cedar Blazek
U.S. Department of Energy

https://www.nrel.gov/docs/fy22osti/82447.pdf

TABLE OF CONTENTS

Project Overview

- *Blokable is developing an integrated multifamily development product that is:*
  - *Net-zero energy*
  - *Affordable AND profitable*
  - *Comfortable*
  - *Environmentally forward-thinking*
  - *Ahead of policy*



  - *How can we utilize their proposed scale up to reduce both operational carbon and embodied carbon?*
    - *IF we built 400 units a year, what happens to the cost and performance model?*
      - *10,000?*

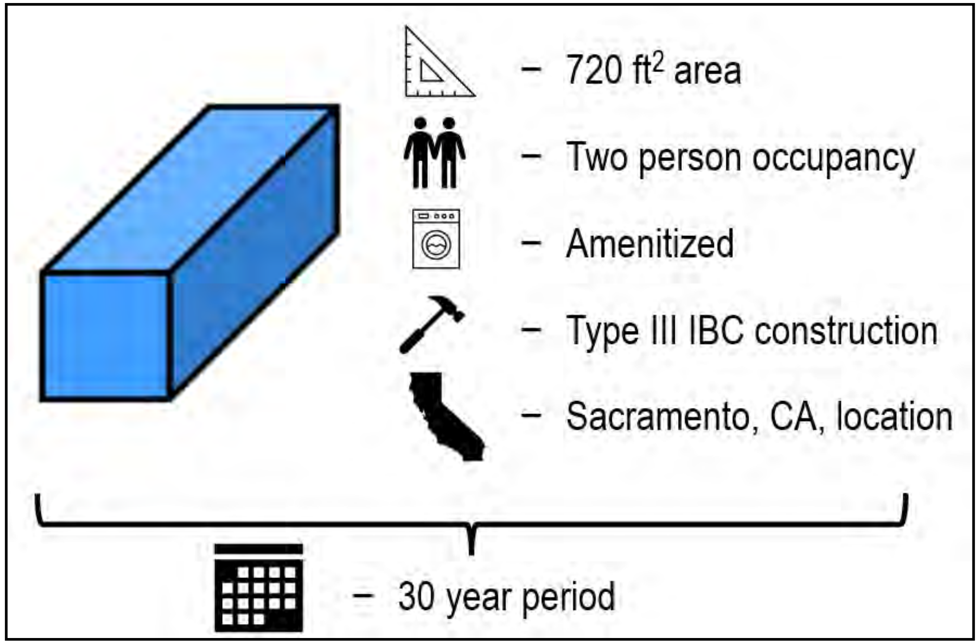
Productization, Standardization, & Manufacturing

Photo from Blokable

Methodology

Modeling the product's roadmap

	Pre-build Product Development Phase	Industrialized Construction Phase	Advanced Manufacturing Phase
	2016 - 2020	2021 - 2025	2026 - 2030
Production Volume	x 1	x 400	x 10,000
Production Capabilities	Smaller Prototyping Facilities	Large Industrialized Construction Facility or Off-site Factory	Multiple Large Manufacturing Facilities

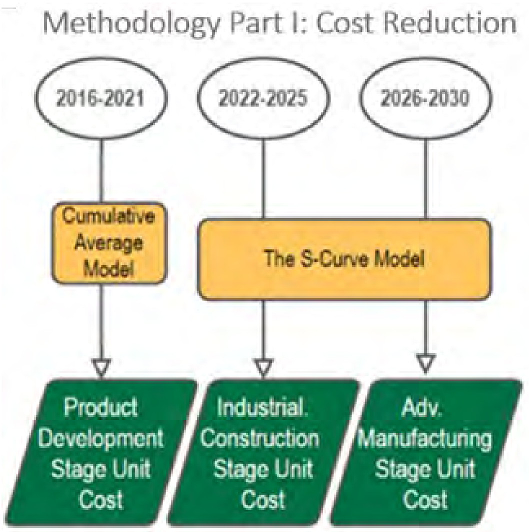


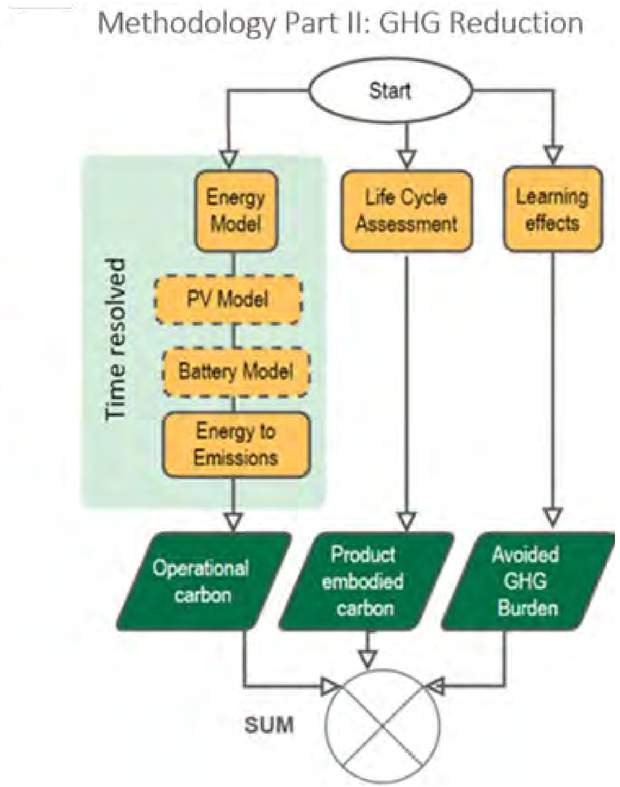
- Economy of scale
- Learning effects
- Leverage vertical integration for long-term savings & affordability

- LCA model
- Scale up 1 apartment to 10k units

Methodology

Modeling product roadmap 10 years down the line





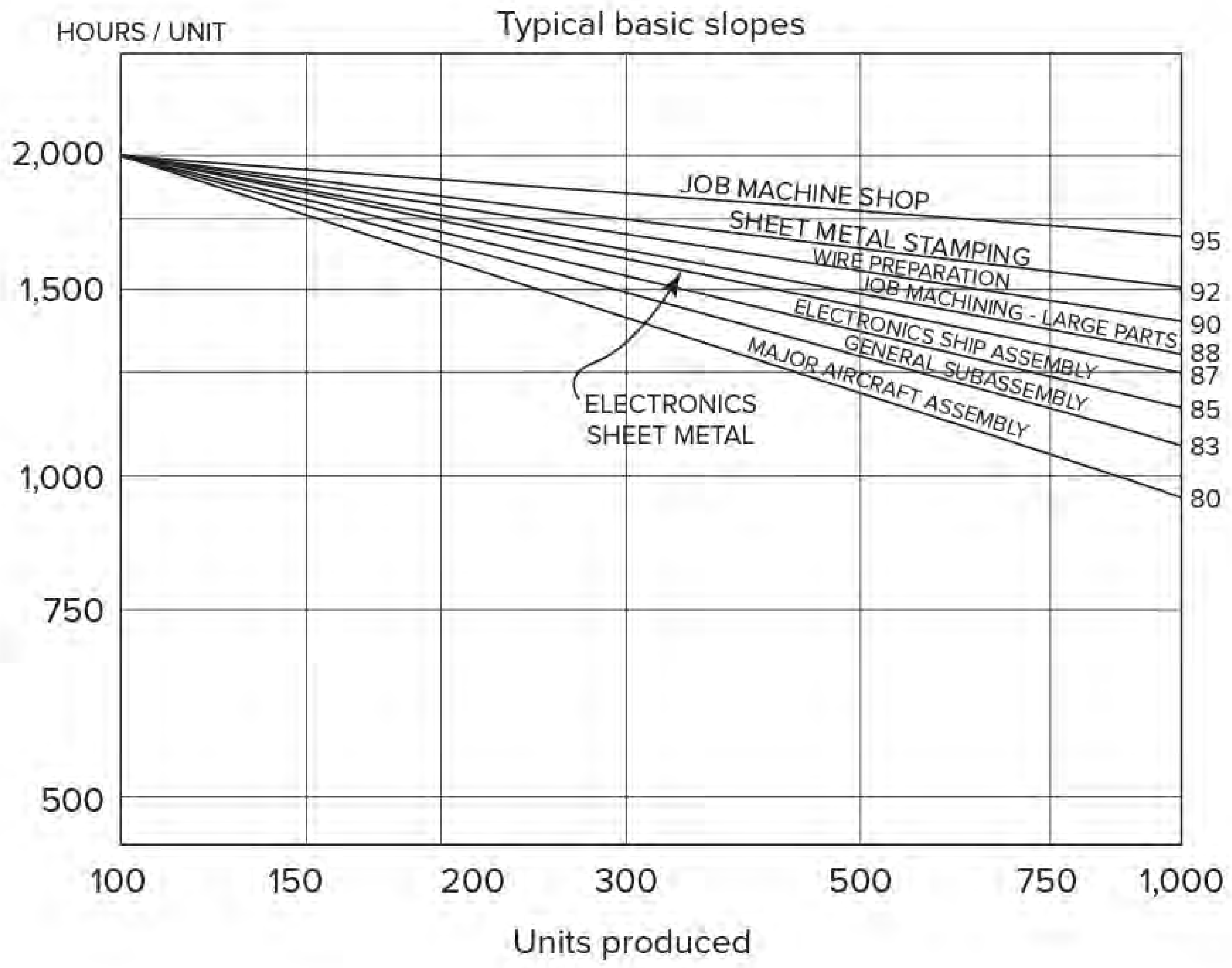
Cost model

- Productivity increase
- Economy of scale
- Reduced waste
- Operational energy savings

Energy & emissions model

- Material decarbonization
- Learning-affected waste reduction
- Grid-responsive technologies
- Operational energy savings

Apply Learning Curves to Modular scale up



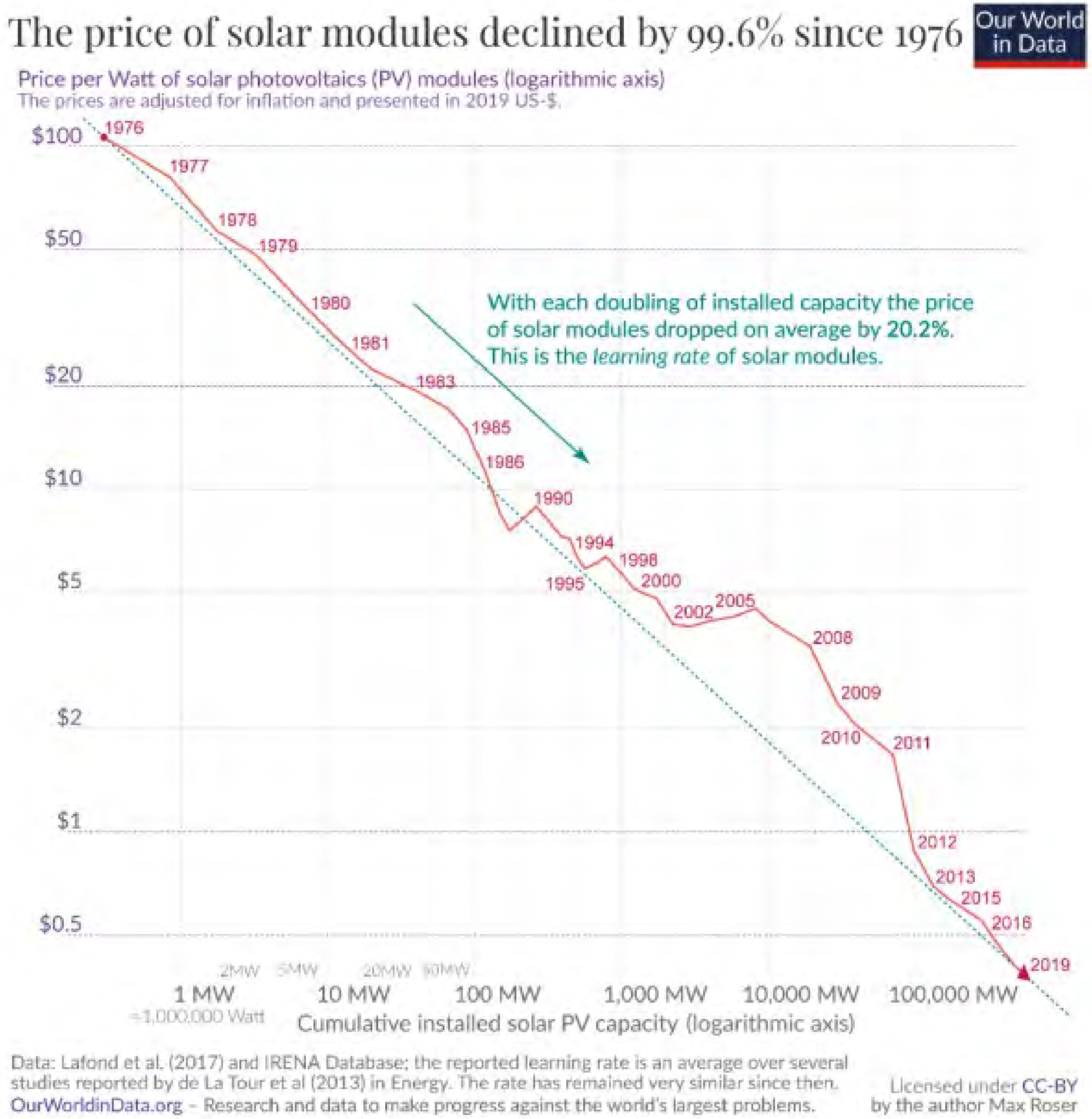


Figure 4. The price of solar modules has declined by 99.6% since 1976

Figure from OurWorldinData.org

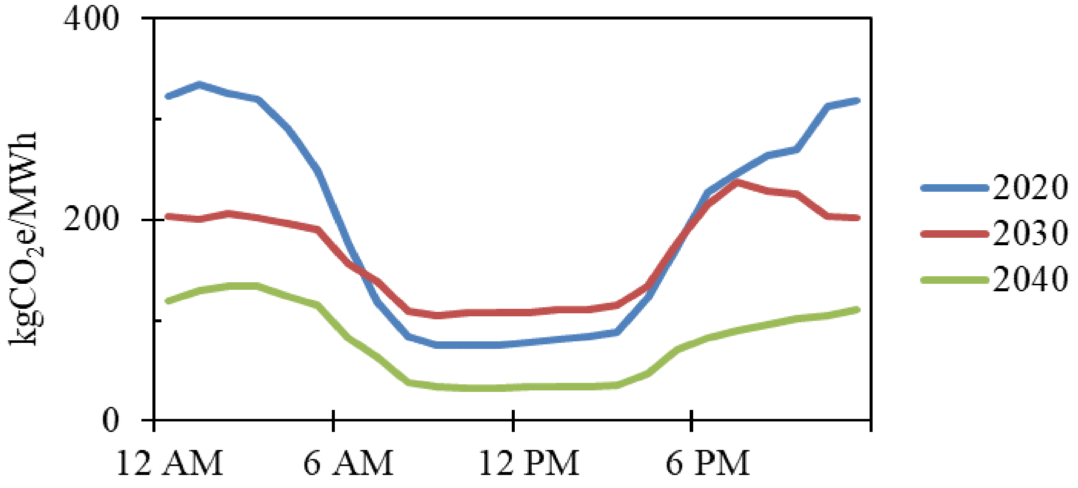
Embodied Carbon Modeling Methodology

Modeling up-front carbon of evolving product line involves policy considerations.

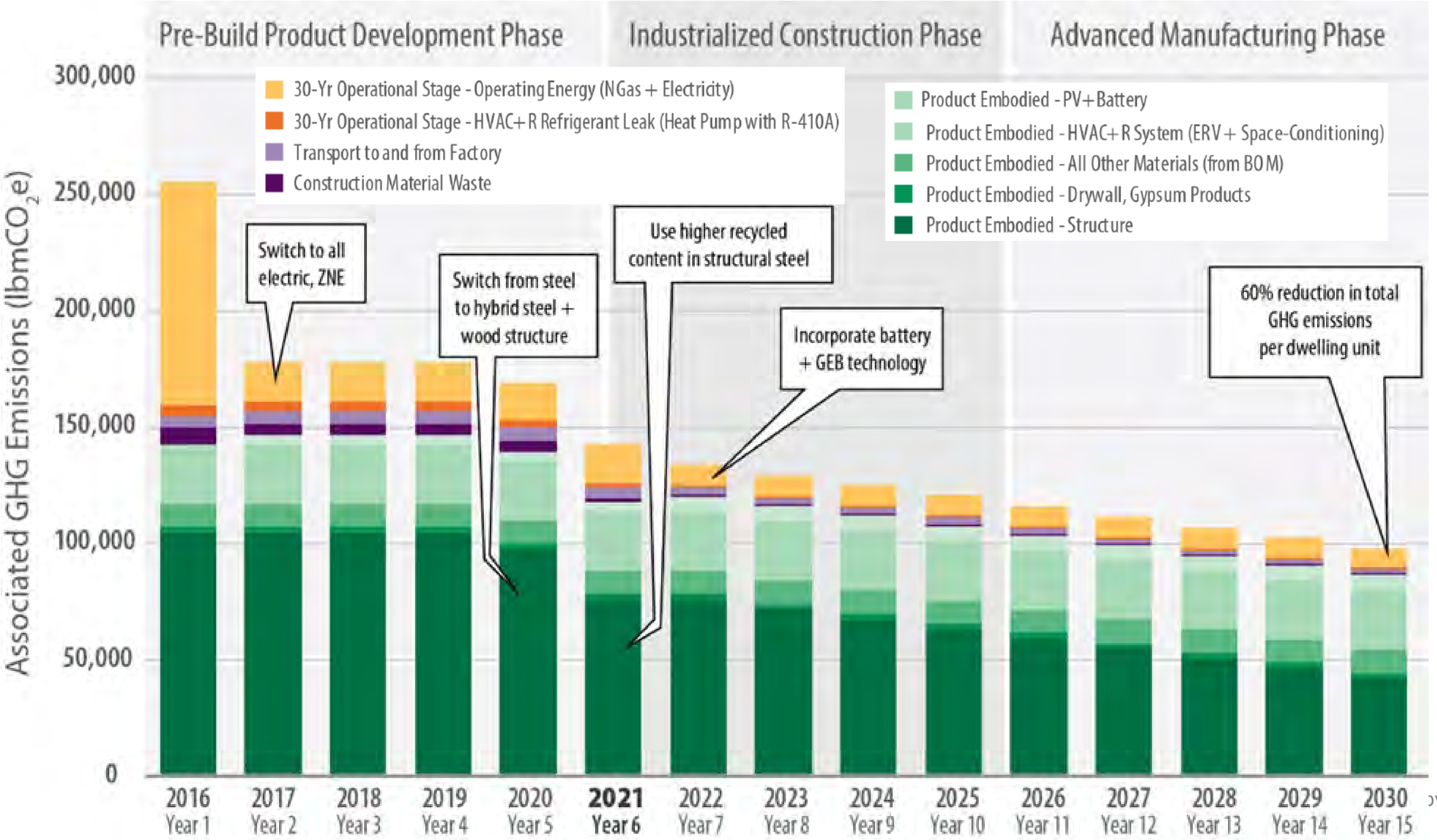
- Buy Clean California Act passed in July 2021 (Bill Track 50 2021)
    - Project steel-related emissions:

Year	2016-2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Steel GWP ($lbmCO_2e/lbm$)	3.05	2.89	2.72	2.56	2.4	2.24	2.08	1.92	1.76	1.6

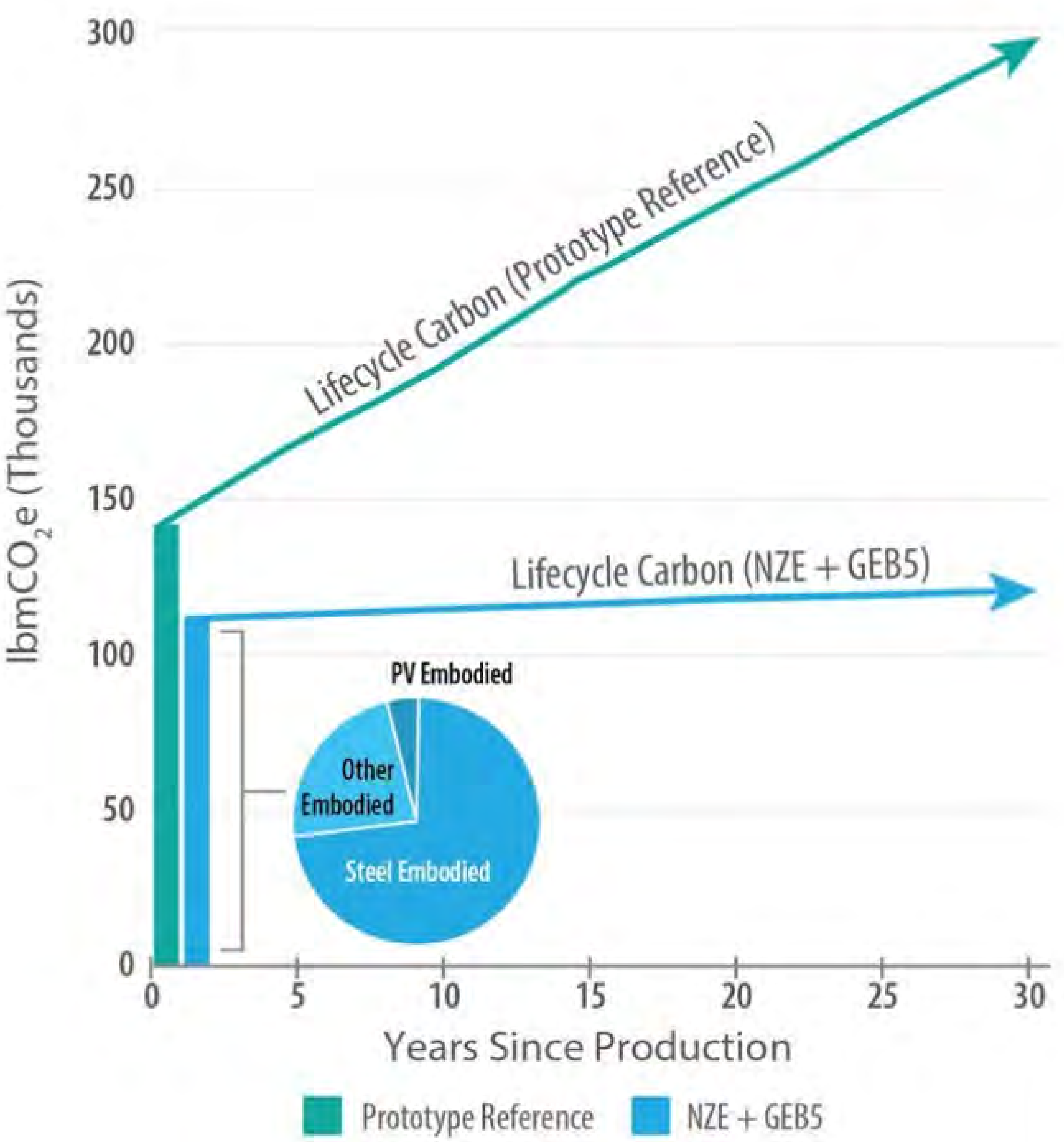
Emissions change as Cambium emissions-factor projections change over time. Effects of decisions are weighed over the lifetime of the building.



Combined lifecycle emissions across product roadmap



y Wells Fargo and NREL



300
250
200
150
100
50
0
lbmCO2e (Thousands)
Lifecycle Carbon (Prototype Reference)
Lifecycle Carbon (NZE + GEB5)
PV Embodied
Other Embodied
Steel Embodied
0
5
10
15
20
25
30
Years Since Production
Prototype Reference
NZE + GEB5

Findings

Path toward decarbonization for vertically integrated developers/builders

- To reduce emissions by 60% by 2030, modular builders should incorporate the following over time:
  - Electrification and carbon-responsive GEB capability well integrated into their standard modular product
  - Factory efficiency to apply learning curves to decarb strategies
  - Waste reduction for materials with high waste factor (e.g., drywall)
  - (Structural) materials with low embodied carbon and high recycled content
  - Design (and commission) for minimal refrigerant and leakage
    - Modular HVAC systems can reduce GHG emissions by up to 20% versus centralized systems

Findings

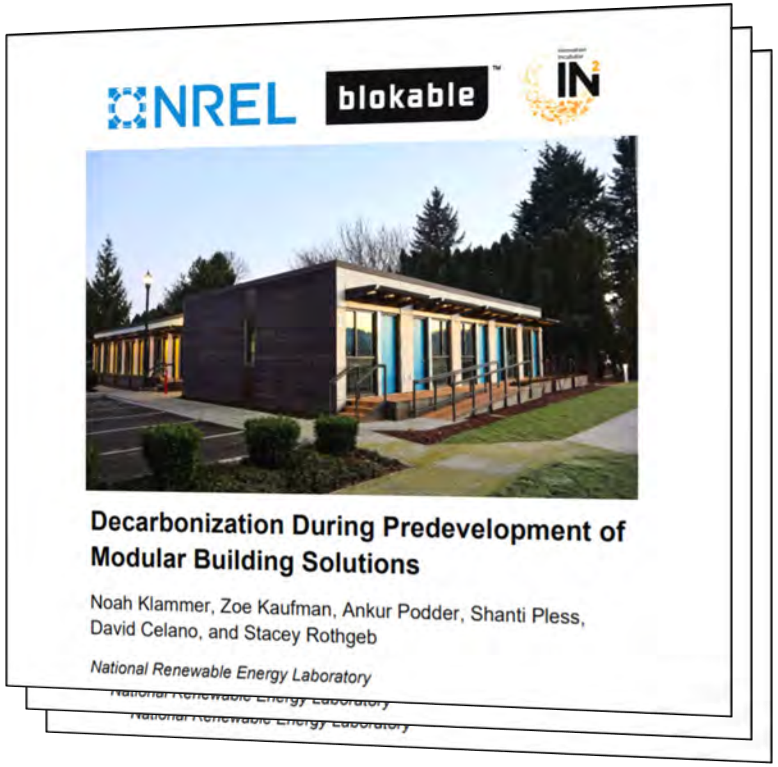
Backdrop for moving toward building decarbonization

- With the aid of **staged planning for emissions reduction of building materials, components, and operations**, integrated developer-owners can create more accurate roadmaps of their own to stage a path for decarbonization
- Product design with decarbonization **included at the beginning of product development lifecycle** necessary to ensure we can leverage learning curves as production ramps
- **60% lifecycle carbon reduction** on a pathway of cost reduction curves

Decarbonization Roadmap & NREL Technical Report

https://nrel.gov/docs/fy22osti/81037.pdf

Google Search:
"**decarbonization during predevelopment**"



Thank you and Questions.

Please reach out: shanti.pless@nrel.gov

We now have methods that can utilize Advanced Manufacturing and Industry 4.0 Industrial Engineering productivity improvement approaches to better integrate complex and decarbonization strategies into the design and construction process MORE cost effectively

- Requires a design that maximizes off-site and prefab approaches
- Leverages productivity gains and repeatability of processes available in factory-built modular

Next Steps:

- Scaling solutions to different regions/factories/building types
- HVAC Pod in 50 units
- ICC Off-Site MEP and Energy Code (out for first draft public review!)