RNC Prefabricated Homes Market Characterization Study (MA21R38)

Final Report

March 24, 2022

SUBMITTED TO:
Massachusetts Program Administrators and Energy Efficiency Advisor Council

SUBMITTED BY:
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Section 1 Introduction

The MA21R38 Residential New Construction (RNC) Prefabricated Homes Market Characterization Study is designed to provide information about how the prefabricated housing market works in Massachusetts and to identify any significant opportunities for the Massachusetts Program Administrators (PAs) to develop offerings that can shift this market toward higher performance practices. This report includes findings from a literature review, interviews with market actors, energy modeling, gross technical potential (GTP) estimates for program offering options, and preliminary suggestions for a second phase of research.

This report covers manufactured and modular homes – together referred to as prefabricated homes – and describes differences in how they are built and brought to the market. Prefabricated homes are constructed off-site in controlled manufacturing facilities and typically fall into two major categories, **manufactured** and **modular** homes.[1]

Manufactured (HUD) homes are subject to the Manufactured Home Construction and Safety Standards promulgated by the U.S. Department of Housing and Urban Development (HUD), rather than local energy codes.[2] People often think of these as mobile homes, though technically only models built prior to 1976 are mobile homes; newer models are manufactured homes.[3] **Manufactured homes are often referred to as *HUD homes*; the report uses that language for brevity's sake.** In addition to meeting various requirements based on federal regulations, they are at least 320 square feet, are built on a permanent chassis, and are transported to their site in one or more sections. Even if they are permanently sited, the chassis remains, allowing for the possibility of future relocation, though relocation is challenging and can damage the units.

Modular homes, like HUD homes, are built in sections in a controlled environment and transported to their final location. However, they have no permanent chassis, are typically installed on a permanent footing or foundation, and accordingly, are subject to the same energy code as traditional site-built homes.[4]

This report covers all sectors of the prefabricated housing market, from low-cost HUD homes to high-cost modular homes.[5] Currently the PAs' RNC program does not focus on prefabricated homes. With a more information, the PAs can assess what potential opportunity exists in the prefabricated market and decide whether an offering in this market is feasible.

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[1] Panelized homes are subset of modular construction. Pre-made components are transported and assembled on-site. They were not often discussed in literature or by stakeholders. As a result, the report focuses on HUD/modular homes.
[2] "Mobile Home Construction and Safety Standards," *40 Federal Register 244 (18 December 1975), pp.58752-58792*, https://www.ecfr.gov/cgi-bin/text-idx?SID=a2c5655a37054c584f7dd6a0ed240fb8&node=pt24.5.3280&rgn=div5.
[3] "About HUD's Construction and Safety Program," U.S. Department of Housing and Urban Development, https://www.hud.gov/program_offices/housing/rmra/mhs/csp/mfsheet.
[4] "Manufactured Housing and Standards – Frequently Asked Questions," U.S. Department of Housing and Urban Development, https://www.hud.gov/program_offices/housing/rmra/mhs/faqs.
[5] Phase 1 serves as a preliminary market characterization. Phase II will be scoped in consultation with the PAs.

Phase I research tasks. This report summarizes findings from the first research activities conducted as part of Phase I of this study, which include the following tasks.

Program staff interview. The team conducted a preliminary interview with implementation staff and the PAs to identify research priorities and background information.

Review of existing literature. The team compiled and summarized existing literature and secondary data on the structure and size of the regional prefabricated housing market and gathered secondary data sources to help quantify the size and efficiency practices of the market relative to the site-built market.

In-depth interviews (IDIs) with market actors and stakeholders. The team conducted 10 IDIs with market actors and industry stakeholders in the prefabricated housing market. Due to small sample sizes and differing respondent backgrounds, findings from the interviews should be treated as qualitative and not representative of the entire market.

Prototype energy modeling and gross technical potential (GTP) savings estimates. The team developed 27 prototype homes, based on four core design templates modeled at various efficiency levels. The four core design templates include:

- a HUD home (modeled at six efficiency levels),
- a single-family modular home (modeled at three efficiency levels),
- a multifamily modular end unit[6] (modeled at three efficiency levels), and
- a multifamily modular interior unit[7] (modeled at three efficiency levels).

Prototypes were modeled under two HVAC and domestic hot water (DHW) scenarios, one with natural gas equipment and one that was all-electric. We refer to natural gas and gas homes or fuels throughout the report, however we did not model any prototypes with propane. Energy consumption results for propane homes would be comparable to natural gas results. The energy model results were used to develop preliminary estimates of GTP savings for the prefabricated homes market, to help inform potential future PA offerings. GTP savings represent an estimate of what savings might exist if all new HUD and/or modular homes achieved the level of savings described in the modeling task. It does not describe achievable or economic potential; it represents an upper bound of savings and is not what we would expect the program to achieve.

Additionally, all **consumption and savings values presented in this report are based on site energy**, which represents the energy consumed by the building onsite, as opposed to source energy, which represents the amount consumed to supply the energy consumed onsite.[8] This report focuses on the consumption values that customers would experience, hence using site energy. These values have not been converted to source values.

Planning for Phase 2. The team will describe the results of this Phase 1 research to the PAs, and work with the PAs to determine 1) if the PAs want to continue to investigate the potential for a program offering that focuses on the prefabricated housing market, and 2) what, if any,

[6] Unit located at the end of the building, with greater exterior surface area.
[7] Unit located in the middle of the building, with less exterior surface area.
[8] https://www.energy.gov/eere/analysis/energy-intensity-indicators-terminology-and-definitions

additional follow-up research would help inform that effort as part of the second phase of this study. This report includes potential Phase 2 research topics that might inform these decisions. The team will provide an additional memo on potential Phase 2 research activities.

1.1 Report Structure

This report includes the following sections:

- Section 2 Summary of Key Findings: A compilation of the findings and results from the prefabricated homes market.
- Section 3 Potential Program Opportunities and Future Research Topics: Details potential program opportunities and future research opportunities. Some of these will be leveraged for the Phase 2 research scoping memo, to be delivered after this report is final.
- Section 4 Research Methodology: details the research methods used for the study.
- Section 5 Prefabricated Housing Industry Overview: A review of prefabricated homes and energy codes.
- Section 6 Prefabricated Housing Market Size and Trends: An assessment of the size of the prefabricated housing market in Massachusetts and industry trends.
- Section 7 Prefabricated Home Costs: Estimates of the cost to construct prefabricated homes.
- Section 8 Prefabricated Market Actors and Supply Chain: Description of supply chain and market actors.
- Section 9 Energy Efficiency in Prefabricated Homes: Energy performance of prefabricated homes.
- Section 10 Savings Potential in the Prefabricated Homes Market: Prototype energy model results and preliminary estimates for gross technical savings potential.
- Appendix A: Specific players and HUD home communities.
- Appendix B: Relevant energy-efficiency programs for prefabricated homes.
- Appendix C: References included in literature review.
- Appendix D: Prototype energy model inputs

In each section, results are separated into subsections on HUD and modular homes. Qualitative results from interviews are presented alongside information gathered during the literature review.

Section 2 Summary of Key Findings

The following section provides key findings from the literature review, interviews with market actors, and energy modeling and GTP estimates.

2.1 Prefabricated Home Market Size

Size of the prefabricated housing market and market trends. Traditional, site-built homes dominate the single-family and multifamily new construction markets, limiting the current opportunity for energy savings associated with new HUD or modular homes in Massachusetts.[9] Interviews with market actors and stakeholders and results from the literature review indicated that growth is anticipated, especially in targeted market segments, such as multifamily and affordable housing, which may lead to greater savings opportunities in the future.

Annual shipments of new HUD homes into Massachusetts averaged only 184 units since 2014, and only 114 in 2020, comprising only 1.5% of the single-family RNC market.[10] New York and Pennsylvania receive far more HUD home shipments (annually around 1,500 in each), suggesting that those states have greater savings potential than the smaller Massachusetts HUD market (see Table 4 for more detail). There are no HUD home manufacturers or dealers in Massachusetts; purchasers work with firms headquartered out-of-state. Interviewees also reported significant consolidation in the HUD manufacturing industry. There are 12 HUD home manufacturers in the Northeast (eleven in Pennsylvania and one in New York), all of which are ENERGY STAR certified.[11] The Pennsylvania facilities account for 90% of HUD homes shipped into the Northeast.[12]

The single-family modular market has grown slightly in the Northeast market over the last decade, but it typically comprises between 5% and 8% of new single-family units.[13] The multifamily modular market (buildings with five or more units) has seen substantial growth over the past two years (estimated 47% growth in the Northeast) and is estimated to comprise roughly 6% of new multifamily units in Massachusetts.[14] Figure 1 describes the estimated number of residential units built or installed in Massachusetts each year, separated by market segment (single-family and multifamily) and construction type (site-built, modular, HUD, and other).

[9] U.S. Census Bureau. Annual Characteristics of New Housing, https://www.census.gov/construction/chars/.
[10] U.S Census Bureau. Shipments of New Manufactured Homes, https://www.census.gov/data/tables/time-series/econ/mhs/shipments.html.
[11] Systems Building Research Alliance. "Plants Certified to Produce ENERGY STAR Manufactured Homes," https://www.research-alliance.org/pages/es_plant_list.htm.
[12] Manufactured Housing Institute, "2021 Manufactured Housing Facts Industry Overview," https://www.manufacturedhousing.org/wp-content/uploads/2021/05/2021-MHI-Quick-Facts-updated-05-2021.pdf.
[13] U.S. Census Bureau. Annual Characteristics of New Housing.
[14] Modular Building Institute, "2020 Permanent Modular Construction Report," May 2020, https://www.modular.org/documents/public/images/PDFs/MBI-PMC-annual-report-2020.pdf.

Figure 1: New Homes Built/Installed in Massachusetts, by Type and Construction Method

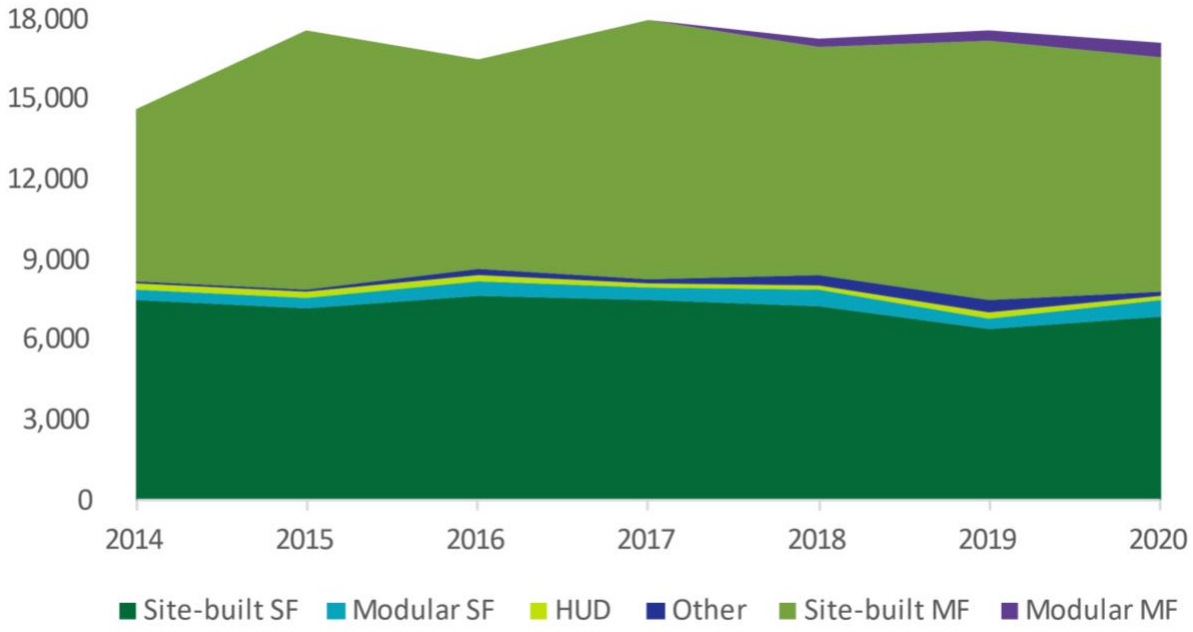

Table 1 provides the underlying data, showing how many housing units are built in Massachusetts annually, by type, including the relative portion of the single-family or multifamily market comprised by that housing type. Section 6 provides additional details.

Table 1: Estimated New Residential Units by Construction Type in Massachusetts

Year	Total[3]	Single-Family[1]								Multifamily[2]			
		Site-Built	% of SF	Mod	% of SF	HUD	% of SF	Other[4]	% of SF	Site-Built	% of MF	Mod[5]	% of MF
2020	17,139	6,917	89%	615	8%	114	1%	154	2%	8,771	94%	568	6%
2019	17,555	6,405	86%	437	6%	190	3%	437	6%	9,700	96%	386	4%
2018	17,244	7,300	87%	574	7%	200	2%	328	4%	8,579	97%	263	3%
2017	17,941	7,531	91%	405	5%	213	3%	162	2%	9,630		-	
2016	16,507	7,634	88%	594	7%	219	3%	254	3%	7,806		-	
2015	17,617	7,161	91%	462	6%	193	2%	77	1%	9,724		-	
2014	14,647	7,528	92%	401	5%	161	2%	78	1%	6,479		-	

[1] Single-family includes buildings with one to four units.
[2] Multifamily includes buildings with 5 or more units.
[3] Uses Census data for HUD home shipment counts for Massachusetts.
[4] Includes different types of system-built homes (e.g., panelized wall, precut units, and log homes).
[5] Modular multifamily estimates based on secondary data; 2020 assumed same rate of growth as 2019 over 2018.
- Insufficient data.

HUD homes represent an affordable housing option. However, HUD homes represent a small portion of the new construction market, less than 1% of new units in 2020. The extent to which new HUD homes are purchased by owner-occupants or as rental units is unclear, but rental units

represent over 80% of all existing manufactured homes in the state (including both newer HUD and older mobile homes). Like most existing HUD/mobile homes (over 90%), most new HUD units are generally installed in park communities. Plymouth County contains the largest share (21%) of existing HUD/mobile homes in Massachusetts, followed by Bristol and Hampden counties (15% and 14%, respectively), and likely represents the bulk of new installations as well.[15]

HUD home manufacturers recently expanded their offerings to include CrossMod homes, a more upscale option that blends manufacturing efficiencies of HUD homes with some of the amenities of modular and site-built homes, such as higher roofs, attached garages, and increased energy efficiency relative to the minimum HUD code, to appeal to buyers of traditional homes.[16]

While the demand for modular housing has remained relatively flat in recent years in Massachusetts, interviewees projected demand for modular projects will increase, especially in the multifamily sector. Advantages such as faster and more reliable construction timelines, lower or more predictable costs, the ability to reduce labor and warehouse materials, and recent financial investments in the industry suggest a strong future for modular housing. The single-family modular home market is dominated by custom homes. Interviewees reported that heavily customizing modular homes interferes with manufacturers' desire to streamline manufacturing but is a necessity for profitability and meeting customer demands. The multifamily modular market, a small subset of the overall multifamily new construction market, has seen strong growth in Massachusetts. Our interviews suggest that this trend will likely continue in the near-term, though monitoring the market in the future would be needed to confirm the accuracy of these predictions.

2.2 Prefabricated Home Costs

Prefabricated housing costs. HUD homes represent a low-cost housing option. New single-wide models[17] in the Northeast cost less than $60,000, on average. Costs vary depending on layout, size (i.e., single-, double-, and triple- wide units) and selected customization options, but typically fall within a much tighter range than modular or site-built homes. HUD homes are considered chattel, or non-real estate, property. They depreciate over time, like a motor vehicle or boat, and have less favorable loan terms than traditional mortgages.[18]

Modular homes tend to be less costly to construct than site-built homes due to shorter project timelines (estimated 35% reduction) and economies of scale.[19] Costs for modular homes are more variable than for HUD homes because the former offer more customization options.

Additionally, the COVID-19 pandemic caused supply chain issues that affected pricing and availability of construction materials, which impacted costs for manufactured and modular homes.

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[15] U.S Census Bureau. Physical Housing Characteristics for Occupied Housing Units, https://data.census.gov/cedsci/table?q=S2504&tid=ACSST1Y2019.S2504.
[16] Manufactured Housing Institute, "CrossMod," https://www.manufacturedhousing.org/new-class-of-homes/.
[17] Single-wide homes vary in size but are typically 14 to 18 feet wide and less than 90 feet long.
[18] Manufactured Housing Institute, "Manufactured Home Financing," https://www.manufacturedhousing.org/manufactured-homes-lender/.
[19] McGraw Hill Construction, "Prefabrication and Modularization," https://www.nist.gov/system/files/documents/el/economics/Prefabrication-Modularization-in-the-Construction-Industry-SMR-2011R.pdf.

2.3 PREFABRICATED SUPPLY CHAIN

Supply chain and market actors. The HUD home supply chain shares characteristics with the site-built and modular markets but is unique in its inclusion of retailers or home dealers as an intermediary between the manufacturer and buyer. The manufacturing process is closely regulated by federal code and third-party overseers, including engineers, architects, and building inspectors. ENERGY STAR certified HUD homes are subject to an additional layer of verification focused on energy efficiency. This complicated system of regulation requires coordination between federal, state, and independent entities, making it cumbersome to change construction standards or established manufacturing processes. While purchasers can install HUD homes on privately-owned land, most lease sites in park communities (251 in the state). Forty-one of those communities are resident-owned; residents buy a share in the community rather than owning a specific plot of land (Appendix A). About 24% of units in park communities are in resident-owned communities. Park communities also impose various limits on unit style, location, and occupant behavior.

The modular home supply chain is like that of site-built homes, with additional market actors to fulfill off-site manufacturing, transportation, regulatory, and installation roles. The modular homeowner is responsible for making most decisions, but their choices can be curated and influenced by builders and designers.

2.4 PREFABRICATED HOME ENERGY EFFICIENCY

Energy efficiency. HUD homes are subject to the inefficient energy-efficiency standards of the outdated HUD code, which has not been updated since 1994. The DOE, however, is considering updating the code to a version of the 2021 IECC, potentially including two performance tiers, a lower-performance tier designed for units that cost less than $55,000, and a higher-performance tier for more expensive units. The DOE opened a public comment period on this topic while the original memo covering this research was being drafted (comments closed on November 26, 2021).[20,21]

Based on reviewed literature, ENERGY STAR certified HUD homes yield a 10% energy savings over an identical home built to the federal minimum standards required by the outdated HUD code.[22] The ENERGY STAR penetration among new HUD homes is 30% nationally, 37% in the Northeast, and 80% in Massachusetts.[23] Interviewed stakeholders indicated that HUD homes rarely achieve efficiencies beyond what is required for ENERGY STAR certification due to strict federal oversight over building practices and the need to keep costs low.

The Northwest Energy Efficiency Manufactured Homes Program (NEEM+) serves as a regional high-performance HUD home certification program. It targets approximately 30% savings over an

[20] See Section 4.2.
[21] Washington Post. "After Decades, Biden Plans to Make Mobile Homes Greener, Sparking a Fierce Debate," January 2022, https://www.washingtonpost.com/climate-solutions/2022/01/21/mobile-home-efficiency-climate/.
[22] As discussed later, modeling included in this study suggests the lower tier 2021 IECC proposal being considered by the DOE yields comparable performance to current ENERGY STAR criteria.
[23] Systems Building Research Alliance. "ENERGY STAR Certified Manufactured Homes," 2020, https://www.research-alliance.org/ENERGY_STAR_Manufactured_Homes_Market_Share_Report.pdf.

ENERGY STAR certified model, [24,25] though the NEEM+ prototypes included in this study saved approximately 17%. Scores of energy-efficiency programs in the Northwest incentivize NEEM+ specifications, though uptake in this relatively new program has been low (a single-digit percentage of the HUD market). [26,27]

Interviewees also noted that PA support for high-performance HUD homes would yield significant benefits to a largely lower-income community, providing occupants with lower utility bills, a healthier indoor environment, and more comfortable living spaces, to the extent that upfront costs remain affordable. Achieving high levels of performance in homes that are already subject to heavy regulation remains a logistical challenge.

Modular projects must meet local energy codes. Unlike HUD homes, they are not subject to a rigid set of federal standards. Accordingly, the energy efficiency of modular construction varies as it does with site-built homes. Key drivers of efficiency in modular homes include customer demand and budget, along with manufacturer skill and product offerings (i.e., some manufacturers offer one efficiency level, some offer options). Interviewed stakeholders noted that builders can meet high-performance standards (e.g., Passive House) using modular or site-built construction methods; neither is inherently superior. That said, some noted that factory environments can make it easier to add highly replicable efficiency and QA/QC protocols, though it would require training staff and updating manufacturing processes.

2.5 Barriers in Modular Industry

Barriers and challenges impacting the modular industry. Stakeholders identified the following key barriers for improving energy efficiency in the modular industry:

- demand for highly customized homes in the single-family market conflicts with achieving economies of scale,
- limited customer awareness of modular options (including homeowners in single-family markets and developers in multifamily markets),
- negative associations with HUD/mobile homes being applied to modular homes,
- training necessary for factory staff and modular builders/installers,
- inconsistent state and local building codes, and
- lack of professionals with experience and technical knowledge to set up a factory that builds modular homes (according to a manufacturer), we hypothesize this is further limited when considering setting up factories that manufacture high-performance buildings and components.

[24] NEEM. “NEEM Plus.” https://www.neemhomes.com/neem-plus.
[25] Apex Analytics, submitted to NEEA. “Manufactured Homes Market Progress Evaluation #1,” July 2020, https://neea.org/img/documents/Manufactured-Homes-Market-Progress-Evaluation-1.pdf.
[26] NEEM Manufactured Housing Program Utility Incentive List, https://www.neemhomes.com/s/Utilityincentives_2020-program-year-87te.pdf.
[27] Apex Analytics, submitted to NEEA. “Manufactured Homes Market Progress Evaluation #1”.

2.6 GROSS TECHNICAL POTENTIAL (GTP) RESULTS

Modeling results and gross technical potential savings from a program targeting prefabricated homes. Energy modeling for HUD, single-family modular, and multifamily modular units showed a variety of savings outcomes for future PA program offerings. **All modeled consumption and savings are based on site energy savings (rather than source savings).** Measure-level details are provided in Appendix D. For modeling, baseline energy models for HUD homes are based on ENERGY STAR version 2.0 (ES V2.0); for single-family modular homes, baseline values are based on the single-family user-defined reference home (UDRH); for multifamily modular prototypes, baseline values are based on the multifamily UDRH.

The DOE has suggested updating HUD code to 2021 IECC, but with two performance tiers. Tier 1 would be for lower-cost units and would achieve a lower performance level than Tier 2, which would be for higher-priced models. The study estimated GTP for each performance level.

2021 IECC Tier 1 for HUD homes: an upgrade over the current HUD code, but only comparable to current real-world baseline in Massachusetts (ENERGY STAR Version 2). A HUD home built to the proposed 2021 IECC Tier 1 would perform comparably to the ENERGY STAR Baseline model (1% higher consumption, whether all-electric or fueled by natural gas). The 2021 IECC Tier 2, in contrast, represents a substantial upgrade (15% savings for gas homes relative to a natural gas Baseline home, and 24% for all-electric). *Any PA effort to impact the HUD market should consider that changes to the federal standards may limit savings opportunities, especially if the new HUD code incorporates the higher-efficiency 2021 IECC Tier 2 standards.*

Model performance: all-electric models outperform natural gas counterparts based on site energy usage, and high-performance packages offer significant energy savings over lower-performance alternatives. For each assessed level of performance, the team built an all-electric and natural gas model, holding the building shell constant. Among reviewed models, the electric model always consumed less site energy than a natural gas version built to the same level of shell efficiency. In fact, even a relatively inefficient all-electric baseline home tended to have lower site-level consumption than gas models with far more efficient shell measures. Among reviewed models, it generally required building a natural gas home to Passive House levels before it would consume less site energy than even a far less efficient all-electric home.[28] There are gas savings opportunities described in the modeling results below, but **these are mostly opportunities relative to a natural gas baseline**, given that the all-electric packages usually have the lowest consumption. *Whether for HUD or modular homes, a program encouraging all-electric options would likely contribute to less site consumption overall.*

HUD models showed a wide range of savings from the ES V2.0 baseline, from slightly negative (2021 IECC Tier 1), to as high as 51% (Passive House). Modular models at program levels of efficiency saved between 5% and 11%, while Passive House variants saved as much as 48%.

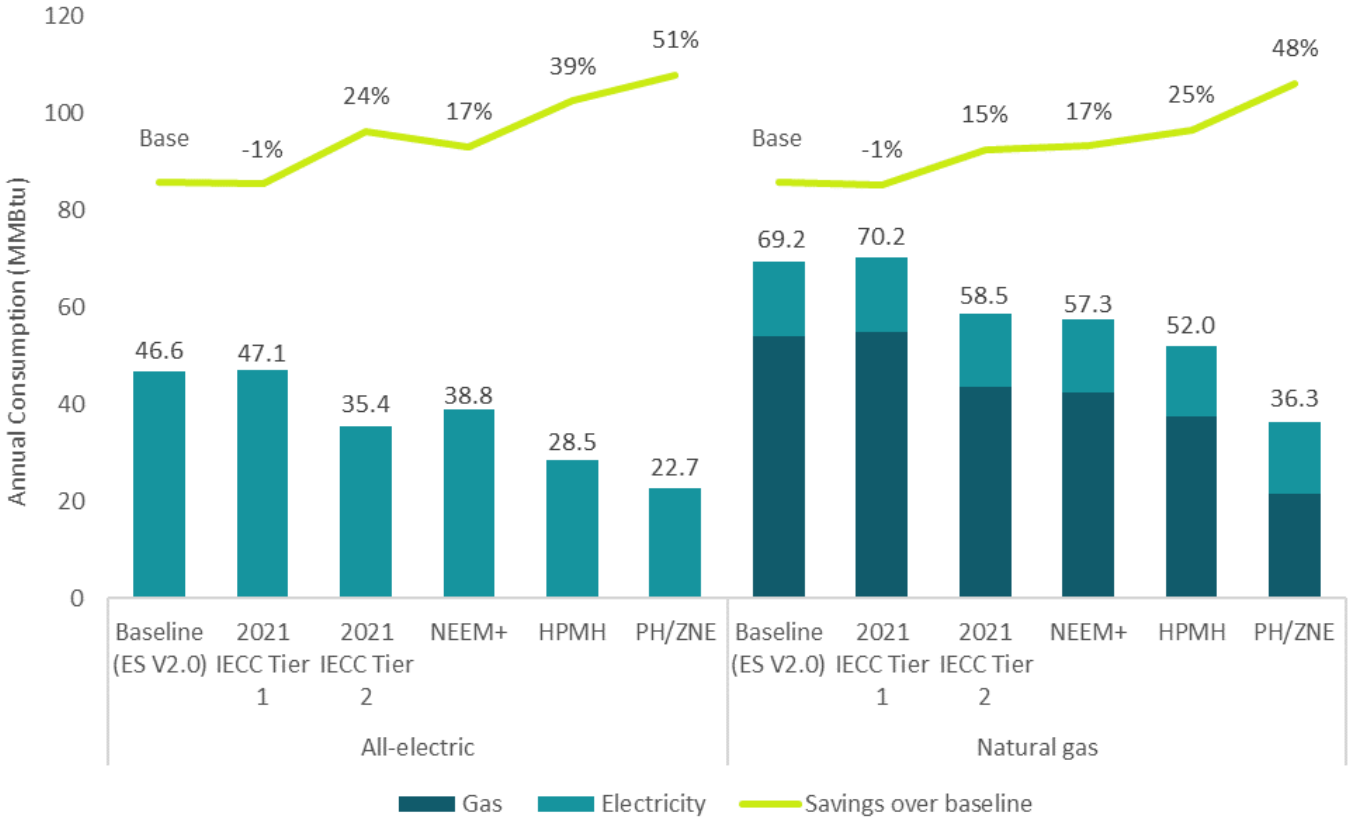
[28] Because electric mechanical systems have higher efficiency ratings than gas systems, each all-electric model had lower annual consumption (site energy) than its natural gas counterpart.

Below we describe the performance of the prototype energy models.

HUD. Except for the 2021 IECC Tier 1 model, all the reviewed HUD models showed savings relative to the Baseline of the same fuel of at least 16% (natural gas 2021 IECC Tier 2), with Passive House models yielding approximately 50% savings (Figure 2).[29]

Of the six natural gas models considered, all but one (the Passive House model) consumed more energy than even the worst-performing all-electric model considered. The natural gas Passive House model consumed less site energy than the all-electric Baseline, 2021 IECC Tier 1, and NEEM+ models, but all of the other natural gas models performed worse than their all-electric counterparts.

Figure 2: HUD Prototype Site Consumption and Savings vs. Baseline (ENERGY STAR V2.0)

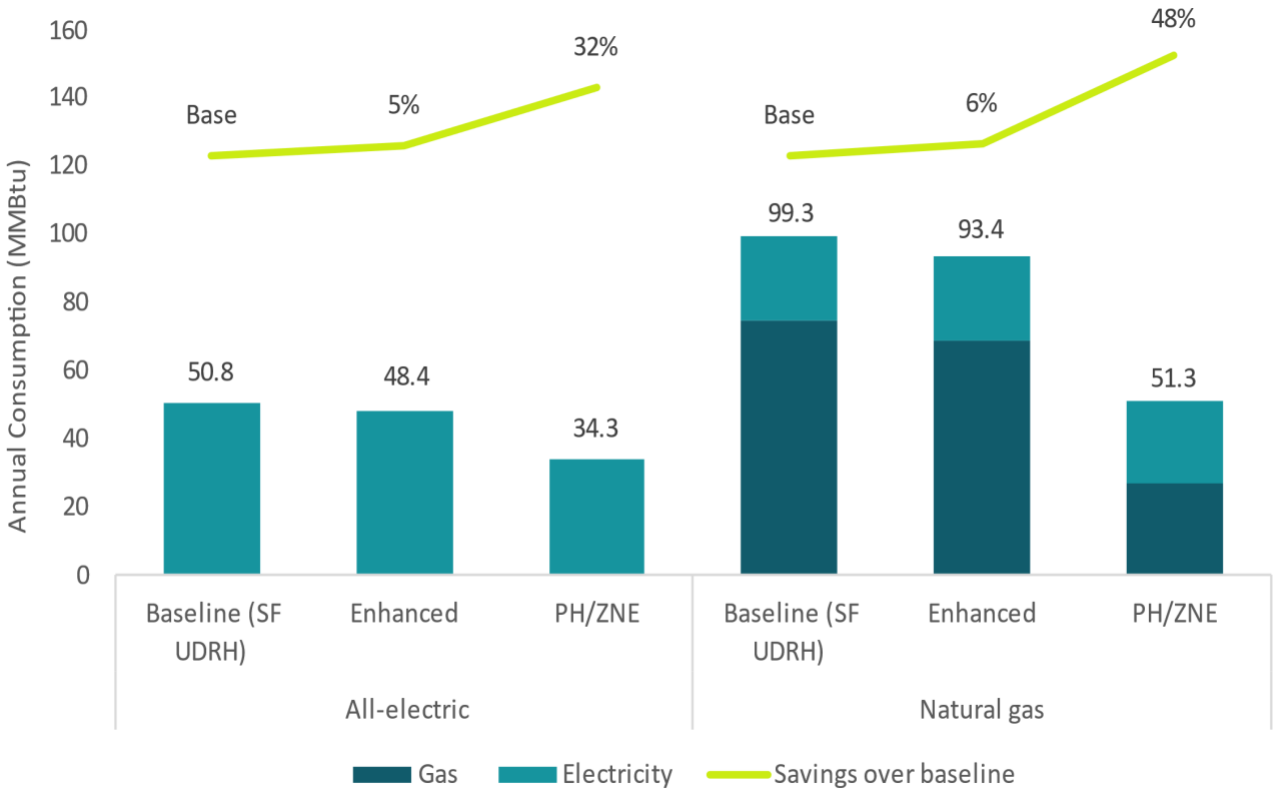


[29] The team notes that the efficiency levels used in the PH/ZNE variation of the HUD home prototype model may not all be physically or financially feasible for HUD homes to achieve.

Single-family modular. No natural gas model outperformed *any* of the all-electric prototypes. The natural gas Passive House model consumed a bit more energy (1%) than even the *Baseline* all-electric variant, which has a far less efficient building envelope.

Models at average RNC program levels of performance (Enhanced) saved 5% to 6% over Baseline versions, but Passive House variants significantly outperform Baseline models (32% savings for all-electric and 48% for natural gas models) (Figure 3).

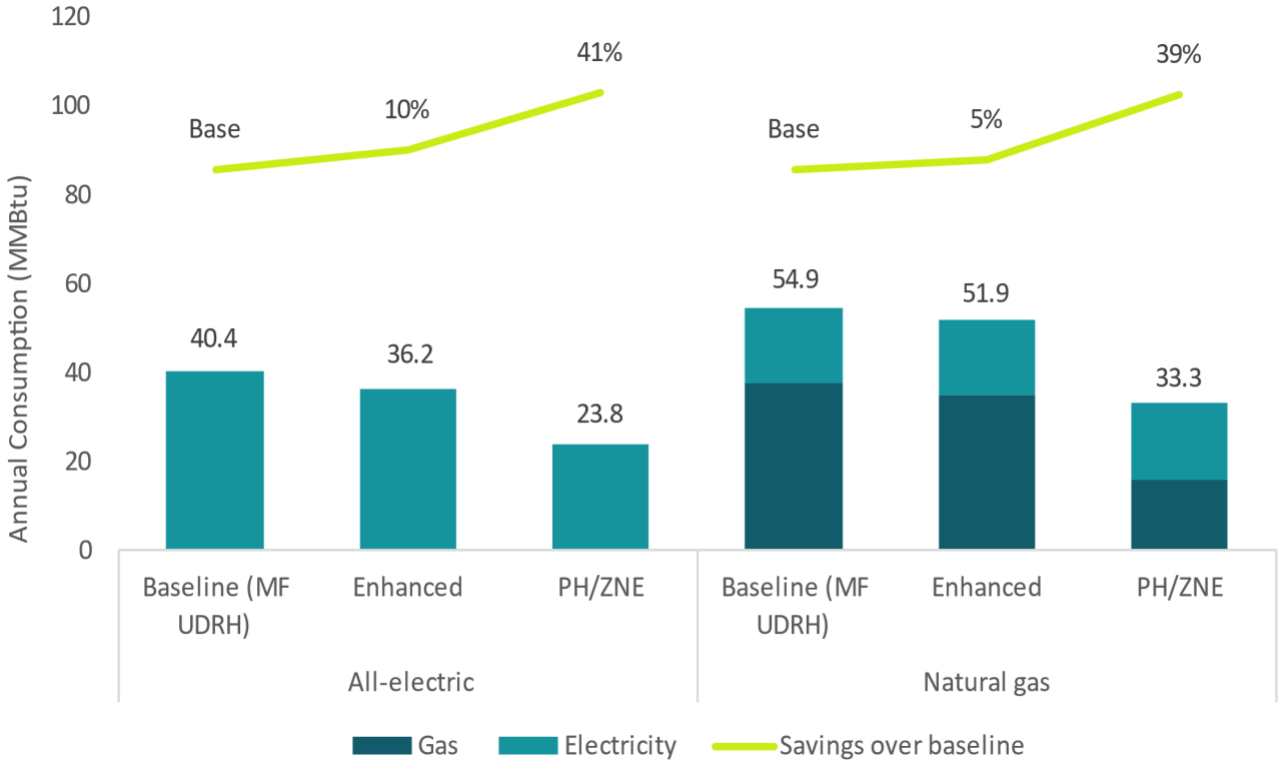
Figure 3: Single-Family Modular Prototype Consumption and Savings vs. Baseline (Single-Family UDRH)



Multifamily modular. The natural gas Passive House model had lower consumption than the Baseline and RNC program level (Enhanced) all-electric models, but the other two natural gas models consumed more energy than even the baseline all-electric model.

The program-level all-electric models saved 10% relative to the all-electric Baseline, and the gas model saved 5% relative to its gas Baseline. All-electric and gas Passive House models saved approximately 40% relative to their Baseline counterparts (Figure 4).

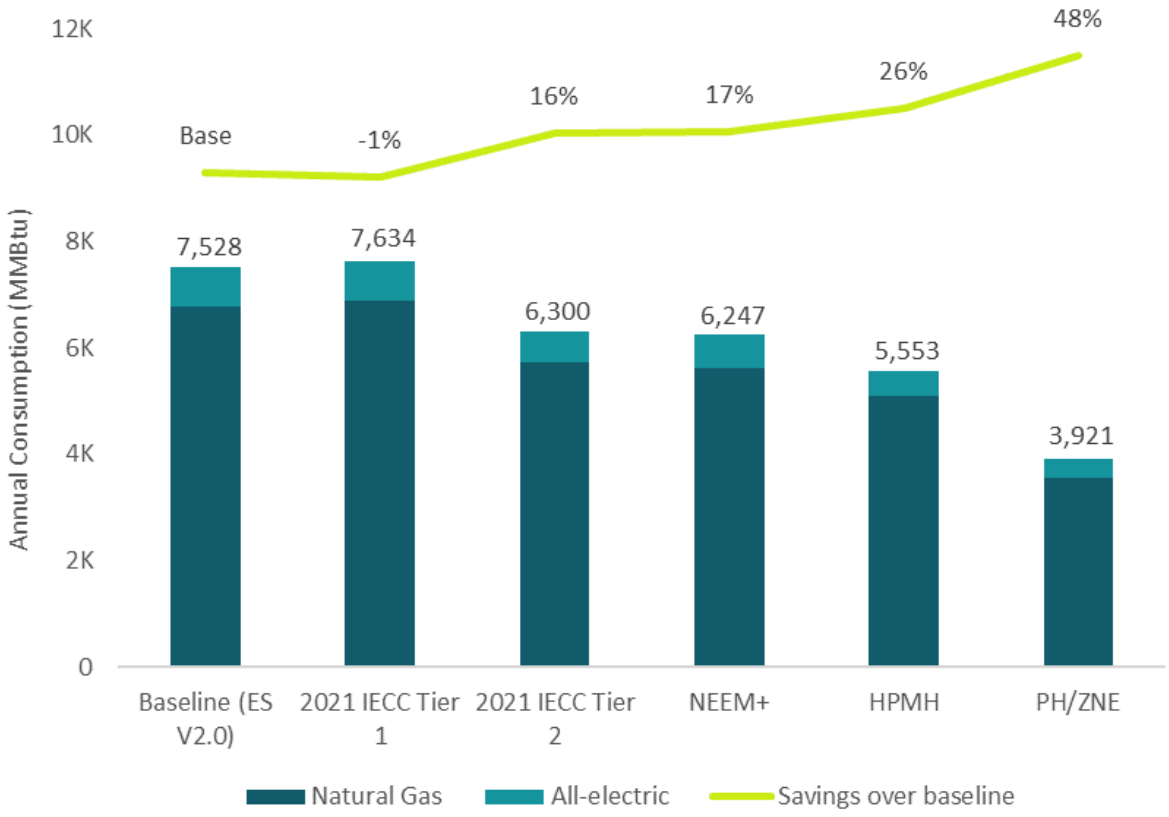
Figure 4: Multifamily Modular Prototype Consumption and Savings vs. Baseline (Multifamily UDRH)



Market-level GTP: all-electric prototypes outperform natural gas models, but market-wide GTP is mostly gas savings due to its prevalence.[30] The following figures (Figure 5, Figure 6, and Figure 7) show prototype model results scaled up to their respective markets. These figures show total annual consumption under each scenario (i.e., if all new prefabricated homes met potential program thresholds) and the resulting GTP, expressed as a savings percentage relative to a baseline scenario. We present multiple GTP estimates for each market segment.

The GTP estimates assume that a program offering would not trigger fuel changes. **Accordingly, natural gas savings opportunities appear greater largely due to the prevalence of gas in new homes.** GTP would increase substantially if the program were to induce changes in fuel choice, from less-efficient gas homes to more efficient all-electric options. Without affecting fuel choice, GTP savings are inherently limited by the higher consumption of gas homes relative to all-electric counterparts. See Section 10 for the data underlying these figures.

Figure 5: HUD Market Annual Consumption and GTP, by Efficiency Scenario



[30] These estimates of GTP assume that 1) all new homes in Massachusetts participate in a PA offer, 2) the homes follow the team's modeling assumptions, 3) achieve the levels of performance described in the modeling, and 4) the relative mix of electric and gas-heated homes follows the proportion seen in the most recent RNC baseline study (for HUD and single-family modular homes: the 2019 19X02 RNC baseline study; for multifamily modular: the 20R30 Multifamily UDRH study).

Figure 6: Single-Family Modular Market Annual Consumption and GTP, by Efficiency Scenario

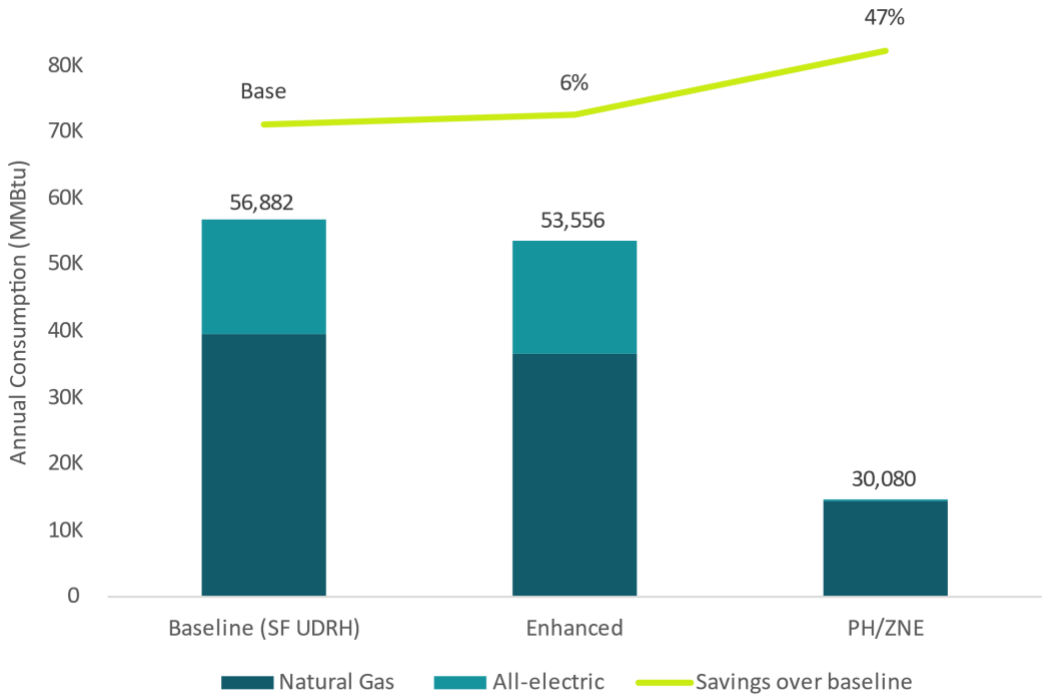
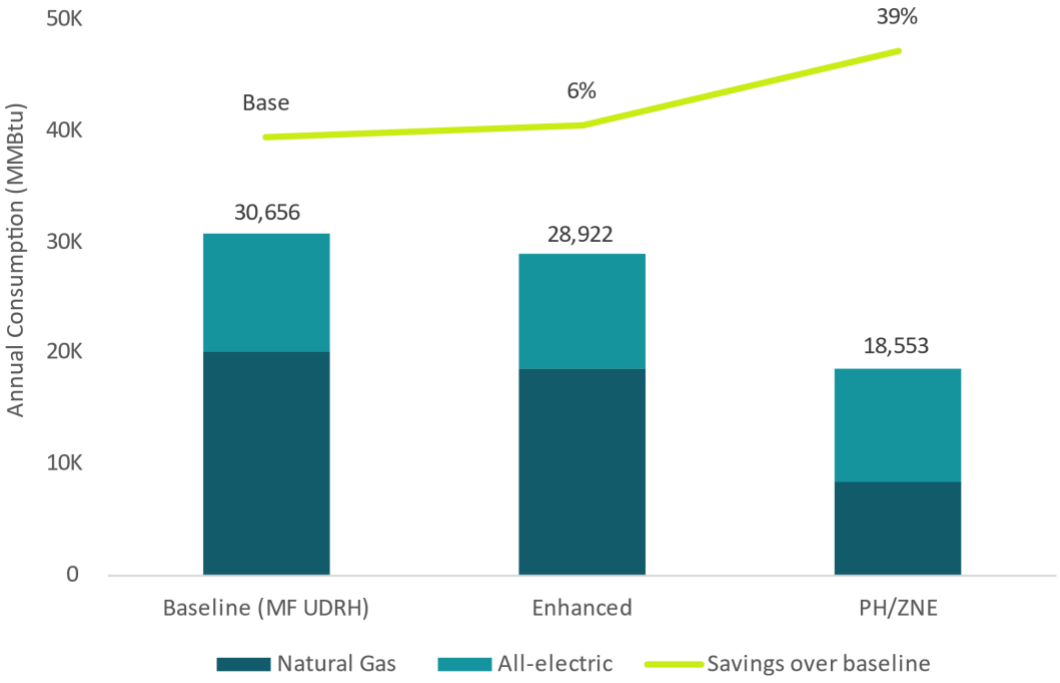


Figure 7: Multifamily Modular Consumption and GTP, by Efficiency Scenario



Section 3 Potential Program Opportunities and Future Research Topics

Based on the results of the Phase 1 research, this section identifies various ways that the PAs might intervene in the new prefabricated housing market. It also suggests potential research topics that could be included in a second phase of this study. **We will revise this list in consultation with the PAs and EEAC consultants and provide a dedicated Phase 2 scoping memo.**

3.1 Program Opportunities for HUD Homes

The opportunity for the PAs to influence the efficiency of HUD homes is limited, largely due to the small size of the HUD home market in Massachusetts (less than 200 new units each year), the high penetration of ENERGY STAR certification among HUD homes (80%), and the complexities of changing standards in a heavily regulated industry. Potential opportunities the PAs have to affect the HUD market include (but are not limited to) the following:

- ***Incentivize ENERGY STAR HUD homes.*** Most new HUD homes shipped into Massachusetts are already ENERGY STAR, but an incentive could serve as a simple entry into the market for the PAs and provide benefits to largely low-income occupants. Designing this as a low-income offering would likely avoid concerns about freeridership and NTG impacts. Such an offer could target individual buyers or institutional investors or developers. Renters (often low- and moderate-income populations) may be the eventual beneficiaries of programs that incentivize higher performance units. Serving this population aligns with the goals of the Equity Working Group established by the EEAC in 2020 and the Low-Income Energy Affordability Network (LEAN). However, the savings opportunity for energy savings is low because: a) there are a limited number of new HUD homes installed in Massachusetts each year, b) most new HUD homes are already ENERGY STAR, according to respondents, and c) ENERGY STAR requirements are only 10% more efficient than HUD code. Any such incentive would likely need to be revisited if the HUD code were to shift to significantly higher energy efficiency requirements (i.e., 2021 IECC levels), as a code upgrade would also likely trigger a change to ENERGY STAR requirements, and the 2021 IECC Tier 2 substantially outperforms the current ENERGY STAR version for HUD homes. The PAs may consider an all-electric incentive as well. Based on modeling, an all-electric ENERGY STAR HUD home consumes approximately 33% less (site) energy than a natural gas-fueled version of the same home, without even considering a higher-efficiency shell.
- ***Bring NEEM+ to Massachusetts.*** NEEM+, based in the Northwest and supported by NEEA, represents an established program that encourages the construction of high-performance HUD homes. Like ENERGY STAR, the program includes prescriptive requirements and structured QA/QC oversight. At a minimum, bringing the program to Massachusetts would require partnerships with market actors and stakeholders and state

and/or federal support. NEEM staff reported they have considered this option for the Northeast but have not obtained funding to do so. Manufacturers of CrossMod homes that already offer above-code options might be reasonable targets for partnership.

- ***Advocate for improved federal standards and participate in the ongoing DOE rulemaking process.*** DOE is considering updating the inefficient HUD code from 1994 to 2021 IECC standards and recently requested public comments on that topic (the comment period closed November 26, 2021). By advocating for an improved code as a part of that or similar regulatory proceedings, the PAs could help improve the entire HUD market and trigger updates to ENERGY STAR standards. Interviewees confirmed that changes to the outdated HUD code are long overdue, and changes would impact the market for a long time to come, based on past trends. Similarly, the PAs could advocate for updated ENERGY STAR standards, though an update of the base HUD code to IECC 2021 may be the most timely opportunity. It should be noted that attributing savings to the PAs' intervention in these standards would be difficult given the number of stakeholders involved.
- ***Incentivize customers to install modular homes in place of HUD homes.*** Such programs exist in Vermont and even Massachusetts (see Appendix B), but uptake is low. In most park communities, occupants do not own the land on which the home sits. Buyers may be hesitant to install permanent modular homes in such a setting, and not all parks would allow it. The potential for such a program appears to be extremely limited and would require significant financial investment and partnership with park communities, affordable housing advocates, and so forth.
- ***Retrofit low-efficiency new units.*** The PAs could immediately retrofit low-efficiency, new HUD homes. Such an offer could provide immediate relief to occupants of these units, but ideally the PAs' efforts would improve the efficiency of HUD homes at the time of manufacture.
- ***Incentivize customers to install new, higher performance HUD homes in place of existing HUD/mobile homes.*** This study focused on the PAs' opportunities to impact the new HUD (and modular) home market, but fewer than 200 HUD homes were installed annually in Massachusetts in recent years (less than 1% of annual new construction). However, there are approximately 22,000 existing HUD/mobile homes in Massachusetts. If the PAs were to incentivize early replacement of existing units in favor of new, efficient models, the savings opportunity would increase substantially beyond just the typical "new" HUD home market.
- ***Build partnerships with market actors and advocate for HUD code to allow for far more efficient levels of performance in HUD homes.*** This study showed the significant savings available for individual HUD homes that achieve extremely high-performance levels, such as to Passive House standards. Incorporating this level of performance into a high-regulated manufacturing process would come with logistical and technical challenges, but the savings benefits to (mostly lower-income) occupants would be substantial. Of course, the small market limits the aggregate savings available, even if individual homes performed well.

3.2 PROGRAM OPPORTUNITIES FOR MODULAR HOMES

Secondary data and market actor insights indicate that while the single-family modular market may be relatively flat in Massachusetts, there appears to be the potential for increased activity in the multifamily sector. As with HUD homes, a program offering geared toward modular homes has limited savings opportunity due to the small size of the market and would also require a multi-pronged approach to achieve significant market impacts. Potential opportunities the PAs have to affect the modular market include (but are not limited to) the following:

- ***Provide incentives for high-efficiency modular units.*** The PAs currently offer incentives to RNC projects that happen to use modular construction. Alternative incentive approaches could include incentives to manufacturers or builders to help build the supply of high-performance modular homes encouraging them to pass along lower costs to buyers. Additional incentives could be provided for market actors such as HERS raters that conduct site visits or trainings to improve practices at modular factories.
- ***Provide incentives for all-electric modular units.*** All-electric packages significantly outperform most of the natural gas scenarios reviewed in the study's modeling effort. A program designed to induce manufacturers/builders to choose all-electric rather than gas modular homes would significantly increase the potential savings available to the program.
- ***Help develop a high-efficiency design template for modular manufacturers.*** The PAs could facilitate the development of modular design templates that manufacturers and developers could use to build replicable projects with predictable performance outcomes that would be eligible for program incentives. A design template could entail a set of architectural, construction, and energy-efficiency specifications, along with manufacturing instructions. This would entail bringing together market actors (e.g., manufacturers, engineers, developers, architects, HERS raters) in a charrette-like process. The process would require significant upfront effort and relationship-building with key market actors. This effort was identified by interviewees as a particularly useful way for the PAs to help influence the energy efficiency of modular construction projects.
- ***Provide technical assistance, training, and support.*** The modular industry would benefit from program technical assistance, training, and other support. A program offering would ideally include technical assistance and training not only for specific projects, but also on how to incorporate high-efficiency specifications and building practices into the production process at manufacturing facilities. The program could work with manufacturers to first identify opportunities that would be easy to implement. Ideal opportunities would include adjustments to specifications or processes the manufacturers could implement without halting production or significantly reconfiguring factory operations.
- ***Develop relationships with regional manufacturers.*** Regardless of the program's specific design, developing relationships with regional manufacturers will likely help ensure success. From providing incentives, to training, to developing design templates, the PAs would need the support of key manufacturers. Industry trends such as consolidation and vertical integration also represent opportunities to influence the modular

market with reduced stakeholder engagement. The limited number of factories, and their fixed locations allow for relationship development and targeted assistance.

- ***Consider non-energy impacts (NEIs).*** A modular program offer should consider NEIs as a part of the program design. The team identified potential NEIs such as: reduced construction waste; safe, well-lit working conditions; healthy (e.g., low-VOC) construction materials; reduced greenhouse gas emissions (e.g., from streamlined, bulk purchasing); or even the embodied carbon of construction materials.
- ***Consider targeting multifamily.*** The growing multifamily market may be an appropriate first target for a modular program offer. Many multifamily projects have simple, repeatable design elements that are well-suited to modular construction. By working with only a handful of manufacturers or developers, the program could help achieve benefits for many occupants. Affordable housing projects may also be ideal initial participants, as these developers may be amenable to developing cost-effective, replicable, and high-performance housing units. Comparatively, the single-family market is small, fragmented, and many projects are highly customized, requiring more effort from the program to fully engage with this market as a part of an early program offering. As a part of building relationships with manufacturers, the program could gather feedback about the feasibility of more aggressively targeting the single-family market.

3.3 Phase Two Scoping Considerations

Phase 1 of this study was designed to characterize the prefabricated homes market in Massachusetts and to assess the potential savings opportunities if the PAs were to design a program that targets these types of homes. In the event the PAs' want to pursue one or more offerings targeting the prefabricated homes market, we provide the following research considerations with the aim to fill in research gaps, test various program design strategies, learn more about drivers and barriers to successful implementation, and develop a program theory and logic model. As noted, we plan to review these considerations with the PAs and EEAC consultants to finalize next steps for a Phase 2 of the study, if warranted.

Conduct program design charrettes with program stakeholders. This process could bring evaluators, implementers, and market actors together to consider what program opportunities the PAs might want to target for the prefabricated market.

Update modeling and GTP estimates based on potential future scenarios. The GTP estimates presented in this report are based on a variety of measure-level assumptions, including the observed prevalence of gas and electric equipment in Massachusetts. Phase 2 could refine any prototype assumptions and consider GTP for any potential program design of interest to the PAs, e.g., one that emphasizes all-electric mechanical equipment. As appropriate, this could include optimization modeling, designed to find packages with low upfront costs.

Estimate GTP of a program that would replace old, inefficient mobile homes with new HUD homes. The market size results from Phase 1 suggest that the HUD market for new homes is small in Massachusetts (approximately 184 units, annually), while there are over 22,000 existing HUD/mobile home units. Accordingly, the PAs may consider a program that targets early

retirement of old HUD/mobile homes. The large pool of existing HUD/mobile homes represents a significant savings opportunity. Participants (owners or renters) of such a program would also benefit from reduced operating costs and other potential NEIs. While challenging, this would likely be a less complicated option than trying to replace old mobile homes with modular units.

Conduct focus groups, design charrettes, or other qualitative research with modular manufacturers and stakeholders to determine the feasibility of various program design scenarios. This qualitative research could cover potential program design strategies, feasibility, technical assistance and support requirements, and incentive amounts. These groups could also be highly technical in nature, helping solicit feedback about how to best create a design template for manufacturers to use on future projects.

Develop a program theory and logic model (PTLM) to inform the measurement of market effects. A successful program targeting the prefabricated homes market could induce market effects. The development of a PTLM to understand what market outcomes could likely occur, the timeframe in which the outcome is expected, and the rationale as to how the outcome leads to market effects would be required to claim market-level savings.

Measure baseline indicators for market effects. After developing a PTLM for any new program offering, evaluators could capture baseline and follow-up measurements of indicators identified in the PTLM.

Additional research targeted at drivers and barriers in the prefabricated market. This research would likely take the shape of in-depth interviews, a web survey, secondary research, or a combination of these. This would focus on not only identifying the barriers and drivers that affect energy efficiency in prefabricated homes, but finding potential solutions to overcome these barriers. Incremental costs, a typical barrier in most new construction market segments, can be assessed in this research as well.

Section 4 Research Methodology

The following section summarizes the research methods included in the study activities to date.

4.1 Program Staff Interview

NMR conducted one group conversation with PA and program implementation staff. During the conversation, the team identified research priorities and gathered relevant background information to help with refining the scope of the study. This information helped inform the content of the interview guide that would be used for stakeholder interviews and helped guide the energy modeling task by identifying what to consider when developing the baseline and upgrade scenarios that will be used to estimate the technical potential savings.

4.2 Literature Review

The team reviewed a variety of relevant studies and literature regarding the prefabricated housing market (see Appendix C for reviewed materials). The review included:

- evaluation reports that covered prefabricated homes (HUD and/or modular),
- websites of manufacturers and retailers that sell prefabricated homes, and
- secondary materials, such as relevant market research and industry reports.

The review focused on the Northeast HUD and modular home markets, gathering information about key players, the size of the markets, the structure of the supply chains, and the energy efficiency of prefabricated homes. The scope of research extended beyond Massachusetts, as prefabricated homes can be built out of state and shipped to an installation site in another state.

NMR used the materials gathered through this review to develop estimates of the size of the prefabricated housing market compared to the more traditional site-built housing market, estimate the number of regional manufacturers and retailers who operate in Massachusetts, and generate a list of prefabricated home manufacturers in the Northeast.[31,32]

The team collected publicly available pricing and efficiency data from regional manufacturers and retailers and identified secondary sources that describe the typical energy-efficiency practices found in prefabricated homes in Massachusetts.

[31] The team did not identify any prefabricated home factories in Massachusetts.
[32] This report uses the U.S. Census definition of the Northeastern region of the United States, which includes the mid-Atlantic states (New York, New Jersey, and Pennsylvania) and the New England States (Massachusetts, Vermont, Connecticut, Rhode Island, New Hampshire, and Maine). https://www.census.gov/programs-surveys/popest/about/glossary/geo-terms.html.

4.3 STAKEHOLDER INTERVIEWS

NMR conducted ten IDIs with market actors and stakeholders in the prefabricated housing market. Interviews addressed topics such as: market structures, key players, how a home moves from manufacture to occupancy, energy efficiency practices, barriers to and costs of high-efficiency practices, adjusting manufacturing processes for high-efficiency practices, and effective intervention strategies—including incentive structures. The team offered a $100 electronic gift card to each interviewee in exchange for their participation in the one-hour interview.[33] Table 2 shows a breakdown of interviewees by profession or area of expertise.

Table 2: In-Depth Interviewees

Respondent Type	Number of Interviews
Modular home manufacturer[34]	4
Program implementer for prefabricated homes	2
Modular home HERS rater	1
Modular home builder[35]	1
Federal code compliance official for HUD homes	1
Industry expert	1
Total	**10**

Readers should note that the preliminary findings from the small number of interviews conducted for this study should be treated as qualitative, and not representative of the entire population of market actors in Massachusetts. In the body of this report, we provide relevant context IDIs along with findings from the literature review.

4.4 PROTOTYPE ENERGY MODELING AND TECHNICAL POTENTIAL ESTIMATES

The team developed a total of 27 prototype homes, based on four core design templates that are modeled at various efficiency levels. The four core design templates include:

- a HUD home (modeled at six efficiency levels),
- a single-family modular home (modeled at three efficiency levels),
- a multifamily modular end unit[36] (modeled at three efficiency levels), and
- a multifamily modular interior unit[37] (modeled at three efficiency levels).

[33] Incentive provided as an electronic gift card to a retailer of their choice, as a Visa gift card, or as a donation to a charity of their choice.
[34] Modular home manufacturers review designs, obtain building permits and materials, and assemble the building envelope.
[35] Modular home builders act as the intermediary between the manufacturer and the home buyer. They work with the home buyer to review design layouts, optional additions, and financing, and work with modular manufacturers to discuss pricing and timeline.
[36] Unit located at the end of the building, with greater exterior surface area.
[37] Unit located in the middle of the building, with less exterior surface area.

Apart from the multifamily modular interior unit, the core prototype designs are modeled under two separate HVAC and DHW system scenarios, one with natural gas equipment and one that is all-electric. The prototypes' characteristics and efficiency levels are detailed in Appendix D.

After running the energy models, the team applied the modeled savings results to the market size approximations to estimate the preliminary gross technical potential savings associated with the prefabricated housing market.

The GTP estimates provide an upper-bound of gross technical savings that would be realized if the programs were to generate the modeled savings for all new prefabricated homes. Future research could estimate achievable or economic potential, which would be much lower and subject to the nature of any prefabricated program offerings by the PAs.

These estimates of GTP assume that 1) all new homes in Massachusetts participate in a PA offer, 2) the homes follow the team's modeling assumptions, 3) achieve the levels of performance described in the modeling, and 4) the relative mix of electric and gas-heated homes follows the proportion seen in the most recent RNC baseline study (for HUD and single-family modular homes: the 2019 19X02 RNC baseline study; for multifamily modular: the 20R30 Multifamily UDRH study).

To develop market-level GTP estimates for HUD and single-family modular homes, we weighted the model results to the estimated market size based on the relative electric and gas fuel mix of baseline homes (e.g., 14% all-electric and 86% natural gas). For low-rise multifamily, we used the fuel mix of 20R30 multifamily baseline homes (6% electric and 94% natural gas). These estimates assume that the program would not trigger changes in fuel choice, only relative efficiency levels for a home with a given fuel. The GTP estimates would be higher than stated if the program promoted a shift away from gas to all-electric configurations.

Section 5 Prefabricated Housing Industry Overview

This section introduces the home types discussed in this report. In this and following sections, the team provides results from the literature review and relevant context from in-depth interviews.

5.1 Housing Types

Non-prefabricated homes.

Site-built homes. Site-built homes are assembled and constructed on the property where they will permanently stand. Site-built construction can be thought of as building with traditional construction methods (i.e., everything from the wood frame to the roof is transported, assembled, and constructed on-site). These are not the focus of the study but are discussed at times as a point of comparison.

Prefabricated homes.

The three home types discussed below fall into the category of prefabricated homes.

HUD homes. Manufactured homes are subject to the Manufactured Home Construction and Safety Standards promulgated by the U.S. Department of Housing and Urban Development (HUD), rather than local energy codes.[38] Per federal regulations, versions built on or before June 15, 1976, are called *mobile homes*; homes built after June 15, 1976, are *manufactured homes, commonly called HUD homes*.[39] HUD homes are constructed in controlled manufacturing facilities and transported in one or more sections on a permanent chassis (e.g., undercarriage) to the property where they will be located. Even if the home is expected to remain in one place, that is, it will be permanently sited, the chassis remains, allowing for the possibility of future relocation. Per federal regulations, HUD homes are dwelling units of at least 320 square feet and display a certification label on the exterior of each transportable section. HUD homes can be combined to create a larger home. Single-wide homes vary in size but are typically 14 to 18 feet wide and less than 90 feet long. Double- and triple-wide homes are single-wide units attached to form a larger home. One interviewed program manager reported that these units typically have a useful life of no more than 30 years, and therefore do not represent an appreciating asset, unlike most site-built homes.

Modular Homes. Modular homes are built in a controlled manufacturing facility, transported to the project-site for installation, and assembled on-site directly onto a permanent foundation. Modular homes are constructed in large sections, called *modules*, which allow for easier transportation from factory to the project site. Modular homes have a label on each

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[38] "Mobile Home Construction and Safety Standards," *40 Federal Register 244,* (18 December 1975), pp.58752-58792, https://www.ecfr.gov/cgi-bin/text-idx?SID=a2c5655a37054c584f7dd6a0ed240fb8&node=pt24.5.3280&rgn=div5.

[39] People often think of these as mobile homes, though only versions built prior to June 15, 1976, are labelled as mobile homes. Only those built after that date are considered HUD homes, under federal law. https://www.hud.gov/program_offices/housing/rmra/mhs/csp/mfsheet.

transportable section to show that they conform to the regulations of the building code where they will be installed (i.e., state, local, or regional building codes) rather than to HUD code.

Panelized Homes. Panelized homes are a type of modular home construction, where smaller components (e.g., sections of floors, walls, ceiling, and roof) are transported to the site in ready-made sections and assembled onsite. Like modular homes, panelized homes must conform to the regulations of the building code where they will be installed (i.e., state, local, or regional building codes) rather than to HUD code. Panelized components can be used in projects that are otherwise site-built and can also be used to construct a modular home within a factory. These appear to be a small portion of the market based on the literature review and stakeholder interviews, so the report focuses on traditional HUD and modular homes.

5.2 GOVERNING ENERGY CODES

HUD code. HUD regulations, sometimes referred to as the *HUD code,* override regional, state, and local building codes. HUD code mandates construction and safety standards, including minimum square footage, number of windows, ceiling height, electrical requirements, ventilation needs, and building materials (e.g., insulation, shingles) for new HUD (manufactured) homes. The HUD code was included in *The National Manufactured Housing Construction and Safety Standards Act of 1974* and became federal law on June 15, 1976.

In 2007, Congress passed the *Energy Independence and Security Act (EISA),* mandating that the U.S Department of Energy (DOE) base HUD code on the most recent International Energy Conservation Code (IECC). While the law required this be completed by 2011, the HUD code has yet to be updated. On July 7th, 2021, DOE committed to establishing energy conservation standards for HUD homes based on the 2021 IECC, which would represent a tremendous increase in baseline performance for HUD homes over the current requirements established in the 1970s.[40] On October 26, 2021, the DOE published a Supplemental Notice of Proposed Rulemaking in this docket, reopening the public comment period regarding changes to the federal code for HUD homes (comment period closed on November 26, 2021).[41] The proposed rulemaking would consider implementing tiered efficiency standards, such that the cost of a HUD unit would determine some of the applicable code requirements, setting more lax requirements for less expensive housing units.[42]

[40] U.S. Dept. of Energy, "Energy Conservation Standards for Manufactured Housing," July 2021, https://www.federalregister.gov/documents/2021/07/07/2021-14484/notice-of-intent-to-prepare-an-environmental-impact-statement-for-energy-conservation-standards-for#footnotes.

[41] U.S. Dept. of Energy, "Energy Conservation Standards for Manufactured Housing: Availability of Provisional Analysis, " October 2021, https://www.federalregister.gov/documents/2021/10/26/2021-23188/energy-conservation-program-energy-conservation-standards-for-manufactured-housing-availability-of

[42] Some industry market actors appear poised to advocate against these standards, arguing that they would drive up the prices of HUD units too much. Example: Manufactured Housing Association of Regulatory Reform, "DOE Takes Next Step Toward Drastic and Costly Manufactured Housing Energy Standards," August 2020, https://manufacturedhousingassociationregulatoryreform.org/doe-takes-next-step-toward-drastic-and-costly-manufactured-housing-energy-standards/

Some industry market actors appear poised to advocate against these standards, arguing that they would drive up the prices of HUD units too much. The team expects the current DOE rulemaking process to include such comments.

> "To us, the primary metric needs to be the upfront cost of the home. … Our concern is that these new requirements are going to make [HUD units] substantially more costly."
>
> *– Mark Weiss, President of Manufactured Housing Association for Regulatory Reform (industry trade group), speaking to Washington Post*

Local energy code for modular homes. Modular homes are required to meet all standard local energy codes, just like a typical site-built home. In Massachusetts, they would need to meet base or stretch code energy efficiency requirements, depending on the municipality where the home is sited.

Section 6 Prefabricated Housing Market Size and Trends

The following section provides additional details about the size of the prefabricated housing market and market trends identified in the literature review and interviews.

Table 3 provides an overall summary of how many housing units are built in Massachusetts annually by type, including the relative portion of the single-family or multifamily market comprised by that housing type.

Table 3: Estimated New Residential Units by Construction Type in Massachusetts

Year	Total[3]	Single-Family[1]								Multifamily[2]			
		Site-Built	% of SF	Mod	% of SF	HUD	% of SF	Other[4]	% of SF	Site-Built	% of MF	Mod[5]	% of MF
2020	17,139	6,917	89%	615	8%	114	1%	154	2%	8,771	94%	568	6%
2019	17,555	6,405	86%	437	6%	190	3%	437	6%	9,700	96%	386	4%
2018	17,244	7,300	87%	574	7%	200	2%	328	4%	8,579	97%	263	3%
2017	17,941	7,531	91%	405	5%	213	3%	162	2%	9,630		-	
2016	16,507	7,634	88%	594	7%	219	3%	254	3%	7,806		-	
2015	17,617	7,161	91%	462	6%	193	2%	77	1%	9,724		-	
2014	14,647	7,528	92%	401	5%	161	2%	78	1%	6,479		-	

[1] Single-family includes buildings with one to four units.
[2] Multifamily includes buildings with 5 or more units.
[3] Uses Census data for HUD home shipment counts for Massachusetts.
[4] Includes different types of system-built homes (e.g., panelized wall, precut units, and log homes).
[5] Modular multifamily estimates are based on secondary data; 2020 multifamily modular estimates assumed the same rate of growth as 2019 over 2018.
- Insufficient data.

6.1 HUD Housing

Number of units. Together, nearly 130 HUD manufacturing facilities produced more than 94,000 HUD units in 2020 in the United States.[43] Massachusetts received only an estimated 114 of these homes, a 40% decrease from 2019.[44] This market is less than one percent of the total residential new construction market in Massachusetts. Table 4 describes annual HUD home shipments into the Northeast, by state.[45]

[43] Manufactured Housing Institute. "2021 Manufactured Housing Facts Industry Overview," last updated May 2021, https://www.manufacturedhousing.org/wp-content/uploads/2021/05/2021-MHI-Quick-Facts-updated-05-2021.pdf.
[44] Modular Home Builders Association. "Modular Home Builders Association Members List, Manufacturers," https://www.modularhousing.com/Links/companylinks.aspx?id=ma.
[45] U.S Census Bureau. "Shipments of New Manufactured Homes," https://www.census.gov/data/tables/time-series/econ/mhs/shipments.html.

Table 4: New HUD Homes Shipped into the Northeast

State	2014	2015	2016	2017	2018	2019	2020	Annual Mean
Rhode Island	11	27	27	38	28	26	50	30
Connecticut	82	79	122	113	105	100	99	100
Vermont	136	144	123	127	121	144	122	131
Massachusetts	161	193	219	213	200	190	114	184
New Hampshire	257	294	381	392	430	394	307	351
New Jersey	284	380	370	471	641	596	479	460
Maine	280	437	539	525	591	635	632	520
New York	1,313	1,333	1,500	1,429	1,604	1,610	1,370	1,451
Pennsylvania	1,322	1,397	1,552	1,545	1,695	1,862	1,648	1,574

Number of manufacturers and dealers. According to the Census, there are 158 firms and 237 establishments operating as HUD manufacturers in the U.S., based on North American Industry Classification System (NAICS) codes.[46,47] Over two-fifths (43%) of the establishments are in Texas (32 establishments), California (20), Indiana (19), Alabama (16), and Tennessee (15). There are 12 HUD home manufacturers in the Northeast —11 in Pennsylvania and one in New York, all of which are ENERGY STAR certified.[48] Pennsylvania alone accounts for 90% of the HUD homes shipped into New England.[49] See Table 20 for a list of the HUD home manufacturers that serve the Northeast.

According to the Census, there are over 1,000 firms operating in 45 states as HUD home dealers (based on NAICS designation). Among the Northeast states, there are currently no HUD home dealers located in Connecticut, Massachusetts, or Rhode Island. States with the most HUD home dealers include Texas (256 establishments), Florida (121), California (118), North Carolina (117), and Louisiana (81).

Consolidation of HUD manufacturers. Four interviewees explained that there is a broad pool of HUD home manufacturers, but the key players are larger companies, such as Champion Home Builders, Commodore Homes, Cavco, and Palm Harbor Homes. Interviewees estimated that these companies produce approximately 90% of all HUD homes in the United States. One interviewee added that there are more modular home manufacturers than HUD home manufacturers due to more opportunity in that market. Interviews and secondary research indicate

[46] The NAICS is a standard used by federal agencies that classify businesses for the purpose of economic data analysis. It defines a *firm* as a business with one or more establishments under the same ownership, within a single geographic area, and in the same industry. NAICS defines an *establishment* as a business with a single physical location.
[47] U.S Census Bureau. "2018 NAICS," https://www2.census.gov/programs-surveys/susb/tables/.
[48] Systems Building Research Alliance. "Plants Certified to Produce ENERGY STAR Manufactured Homes," https://www.research-alliance.org/pages/es_plant_list.htm." 2018.
[49] Manufactured Housing Institute. "2021 Manufactured Housing Facts Industry Overview," https://www.manufacturedhousing.org/wp-content/uploads/2021/05/2021-MHI-Quick-Facts-updated-05-2021.pdf.

that some large manufacturers produce both modular and HUD homes.[50] Manufacturers that build both types of prefabricated homes typically do so in separate facilities.

Upscale HUD homes. Interviewees noted that a relatively new HUD home product, called *CrossMod*, is increasing in popularity for some major manufacturers. CrossMod homes are HUD homes with additional amenities and improved aesthetics, such as higher roofs, attached garages, and increased energy efficiency. They are designed to appeal to buyers of site-built homes.[51] Two interviewees explained that lenders may prefer to finance CrossMod homes because unlike typical HUD homes, they may be less likely to be treated as a depreciating asset. Interviewees further explained that there is controversy surrounding CrossMod homes, as some stakeholders think they should be subject to local building code instead of HUD code.

Park communities. According to the Census, Plymouth County contains the largest share (21%) of existing manufactured housing units in Massachusetts (including HUD and mobile homes), followed by Bristol and Hampden counties (15% and 14%, respectively).[52] The vast majority of HUD/mobile homeowners in Massachusetts do not own the land on which their homes are located, making it challenging for many owners to invest in properties that do not appreciate like homes built on owned land typically do. The Vermont Energy Investment Corporation (VEIC) prepared a report that identified 251 manufactured housing park communities in Massachusetts, and only 41 of which are resident-owned (Table 19).[53] Approximately 24% of spaces in Massachusetts park communities are in resident-owned communities. In total, park communities provide over 20,000 sites across 113 of the 351 municipalities in Massachusetts. Because most existing HUD and mobile homes are in park communities (approximately 94%),[54] we expect that most new HUD homes will also be installed in these communities.

[50] Modular Home Builders Association. "Modular Home Builders Association Members List, Manufacturers," https://www.modularhousing.com/Links/companylinks.aspx?id=ma.
[51] https://www.manufacturedhousing.org/new-class-of-homes/
[52] U.S Census Bureau. Physical Housing Characteristics for Occupied Housing Units, https://data.census.gov/cedsci/table?q=S2504&tid=ACSST1Y2019.S2504
[53] VEIC. Vol 2 ZEMAHI ZEM Market Assessment, September 2020. Report not yet public.
[54] This figure compares the number of HUD units in the state with the number of lots in park communities; some of those lots may be vacant, slightly affecting these numbers.

Own vs. rent. Most HUD homes in Massachusetts are rented (81%) (Table 5). [55]

Table 5: Existing HUD/Mobile Home Housing Units by Massachusetts County and Ownership Status

County	Units	% Owned
Barnstable	114	41%
Berkshire	1,098	1%
Bristol	3,275	8%
Essex	2,086	22%
Franklin	547	36%
Hampden	2,981	17%
Hampshire	698	38%
Middlesex	2,421	39%
Norfolk	678	0%
Plymouth	4,646	9%
Suffolk	1435	31%
Worcester	2,069	33%
Statewide total	**22,048**	**19%**

6.2 Modular Housing

Number of units. According to the Census, modular construction has steadily comprised five to ten percent of the single-family new construction market in the Northeast since 1992.[56] Single-family modular units built in Massachusetts have numbered between approximately 400 and 600 units annually since 2014.

Since 2018, multifamily modular units built in Massachusetts are estimated between approximately 260 and 570. The estimated number of modular multifamily units installed in the Northeast represents 38% of all modular multifamily units sold in the United States. Massachusetts and New York have the most multifamily modular construction outside of California. [57, 58] While this represents a small fraction of all multifamily construction in the Northeast, it does show signs of growth. See Table 1 for underlying data.

Number of manufacturers and builders. The literature review identified over 50 modular manufacturers that ship homes into Massachusetts (Table 21: Modular Home Manufacturers) and 29 modular builders located in Massachusetts (Table 22). No modular home manufacturing facilities appear to be located in the state. The NAICS codes for modular builders and

[55] U.S Census Bureau. Physical Housing Characteristics for Occupied Housing Units, https://data.census.gov/cedsci/table?q=S2504&tid=ACSST1Y2019.S2504.
[56] U.S. Census Bureau. Annual Characteristics of New Housing. Construction Methods, https://www.census.gov/construction/chars/.
[57] Modular Building Institute. "2020 Permanent Modular Construction Report," May 2020, https://www.modular.org/documents/public/images/PDFs/MBI-PMC-annual-report-2020.pdf.
[58] Modular Building Institute. "2019 Permanent Modular Construction Report," May 2019, https://www.modulargenius.com/wp-content/uploads/company-info/Architect-Web-Page-Resources/2019-Permanent-Modular-Construction-Report.pdf.

manufacturers are too broad to use NAICS-based Census data to develop estimates of modular home builders or manufacturers in the state.[59]

Strong demand. Multiple stakeholders noticed a recent increase in the demand for modular homes and reported that this bodes well for the future of the market. During the IDIs, two industry experts estimated that modular homes comprise approximately 15% of residential new construction in Massachusetts, a higher percentage than Census data suggests, potentially an indication of popularity in their market segment. Interviewees opined that increased customer demand is driven by faster or more reliable construction timelines, fewer neighborhood disturbances during installation, and lower or more predictable costs relative to site-built homes. In addition, several interviewees mentioned that the modular market has received significant financial investments to build new manufacturing factories, increase its production, and expand product offerings, particularly for the multifamily market.

Labor and materials. Interviewees described how COVID-19-induced labor shortages in Massachusetts revealed one competitive advantage of modular home building: less reliance on skilled labor due to automation and industrial manufacturing processes that require fewer staff. Other stakeholders discussed how modular home manufacturers are poised to achieve economies of scale, partly through ordering bulk materials at lower rates and shipping them to central locations where they can be stored until needed. One interviewee explained that while the pandemic caused shipment delays and raised the prices for building materials like timber and steel, modular manufacturers' unique ability to store materials helped them sustain short term fluctuations in price or availability.

> "Single-family [modular homes are] often customized, which is the problem. The factory needs a good idea of what is coming in to be consistent, right volume, high enough volume. This is where a program can help out."
>
> *- Industry Expert*

Customizing homes vs. streamlining manufacturing processes. Six of eight interviewees estimated that most single-family modular projects in the Northeast are custom homes. One industry expert estimated that 70% of modular projects in Massachusetts are heavily customized.

The interviewees identified customization as a major barrier to achieving economies of scale. Economies of scale are best achieved by anticipating needs and developing replicable processes throughout the supply chain, including materials procurement, manufacturing processes, transportation requirements, and assembly processes. Customization inevitably complicates and slows down manufacturing and assembly processes, which in turn increases costs. Despite these downfalls of customization, manufacturers also noted that custom single-family projects have higher profit margins and are major drivers of their business.

Interviewees explained that finding new ways to make the manufacturing and assembly processes more efficient should be an objective for any program that seeks to increase efficiency in the modular market. Interviewees noted that manufacturers can and will modify their processes,

[59] The NAICS identifies modular builders under the category of "Prefabricated Wood Building Manufacturing," a category that also includes log cabins, chicken coops, sauna rooms, and sheds.

invest in staff training, and pay more for raw materials if those changes increase factory throughput.

Vertical integration. One industry expert explained that developers around the country are integrating manufacturing factories into their businesses. Consolidating in this way enables them to withstand industry labor shortages, minimize production costs, maintain greater control over construction methods, and more accurately predict project timelines. Vertical integration of the modular industry is happening most frequently in the western and southern regions of the country. While there are several manufacturers in the Northeast that may present an opportunity for developers to vertically integrate, the existing modular factories, combined with regional land constraints, may somewhat insulate the region from this practice.

Multifamily construction. Modular construction is a small but growing portion of the Northeastern multifamily market. Modular multifamily construction is faster than traditional site-built multifamily projects because factories can build the modules concurrently with initial on-site construction, allowing developers to lease or sell projects sooner. After analyzing project costs and timelines for several modular multifamily projects, the Modular Building Institute reported that modular multifamily projects were completed in about half the time as their site-built counterparts.[60,61]

While all modular manufacturing can achieve economies of scale, some multifamily designs are particularly well-suited to modular building. Interviewees indicated that wood-framed buildings with three to five floors and identical residential units along double loaded corridors are most compatible with modular construction methods. These design characteristics allow for significant streamlining of manufacturing processes and bulk material purchases to minimize overall project costs. Modular construction logistics become increasingly complex as building sizes increase, though one interviewee noted that they worked with one modular project that had 17 floors.

Barriers. Interviewees described additional barriers that face the modular industry, such as:

- **limited customer awareness** of modular options (including homeowners in single-family markets and developers in multifamily markets),
- **negative associations** with HUD/mobile homes being applied to modular homes,
- **significant training needed** to build skills for factory staff and modular builders/installers,
- **inconsistent building codes** (state and local), and
- **lack of construction/manufacturing professionals** with experience and technical knowledge to set up modular factories (according to a manufacturer).

[60] Modular Building Institute. “2020 Permanent Modular Construction Report,” May 2020.
[61] Modular Building Institute. “2019 Permanent Modular Construction Report,” May 2019.

Section 7 Prefabricated Home Costs

7.1 HUD Housing

Estimated costs. HUD homes cost significantly less than most site-built homes. They tend to be modestly sized and have limited opportunities for customization. This also keeps pricing within a tighter band than among more customizable modular homes. HUD code allows manufacturers to offer some aesthetic or convenience options along with their core designs, but major customizations at the point of manufacture are prohibited, aside from the ability to combine units. In 2020, the average sale price for a new single-wide and double-wide HUD home in the Northeast was approximately $57,000 and $107,000, respectively, excluding the taxes, cost of improvements, and the price of land (Table 6).[62,63,64,65]

Table 6: Average Price of HUD Homes in the U.S. in 2020

Region	HUD Home[1]	
	Single-wide	Double-wide
Northeast	$58,000	$108,000
Midwest	$57,000	$105,000
South	$57,000	$107,000
West	$62,000	$118,000

[1] Excludes the cost of land; includes dealer fees.

According to interviewees, the price of a HUD home can vary depending on layout and, to a lesser degree, customizations. Unlike most site-built and modular homes, HUD homes depreciate over time. Additionally, if a homeowner does not purchase a parcel of land along with a HUD home, the home is considered chattel property, making it ineligible for conventional mortgages and subject to less favorable loan terms.[66] Approximately 76% of new HUD homes are financed through chattel loans.[67]

[62] U.S. Census Bureau. Manufactured Housing Survey. Average Sales Price of New Manufactured Homes, https://www.census.gov/data/tables/time-series/econ/mhs/average-sales-price.html.
[63] U.S. Census Bureau. Annual Characteristics of New Housing. Sale Price. https://www.census.gov/construction/chars/.
[64] U.S. Census Bureau. Manufactured Housing Survey. Average Sales Price of New Manufactured Homes. https://www.census.gov/data/tables/time-series/econ/mhs/average-sales-price.html.
[65] U.S. Census Bureau. Manufactured Housing Survey. 2020 PUF data, cited in DOE NPRM: https://www.federalregister.gov/documents/2021/10/26/2021-23188/energy-conservation-program-energy-conservation-standards-for-manufactured-housing-availability-of
[66] Manufactured Housing Institute, "Manufactured Home Financing," https://www.manufacturedhousing.org/manufactured-homes-lender/.
[67] Manufactured Housing Institute, "2021 Manufactured Housing Facts Industry Overview," https://www.manufacturedhousing.org/wp-content/uploads/2021/05/2021-MHI-Quick-Facts-updated-05-2021.pdf.

7.2 MODULAR HOUSING

Table 7 provides an itemized breakdown of the costs a consumer may encounter when purchasing a modular home.[68] Costs are based on national averages and should not be considered representative of the Massachusetts market, where prices are typically higher. The ranges reflect different grades of housing, from lower-end to higher-end, with improved amenities, finishes, and other upgrades; all exclude land costs. As the ranges demonstrate, modular homes can be heavily customized and can be designed for a wide range of budgets.

Table 7: Estimated Modular Home Example Costs, National Averages[3]

Project Component	Average Price[1]	Average Price Range[2]
Modular base price	$180,000	$120,000 - $240,000
Land preparation	$7,500	$4,000 - $11,000
Slab foundation	$13,000	$6,000 - $20,000
Basement or crawlspace foundation	$52,500	$25,000 - $80,000
Delivery	$7,500	$3,000 - $12,000
Installation	$30,000	$10,000 - $50,000
Permits	$2,250	$500 - $4,000
Garage	$17,500	$10,000 - $25,000
Deck	$7,000	$4,000 - $10,000
Total Cost:	310,000	$182,000 – $450,000

[1] Prices based on a 1,500 square foot modular home.
[2] Prices vary depending on site circumstances, manufacturer pricing, construction pricing, and optional features, such as garages, decks, and fences.
[3] Excluding price of land.

Cost reduction opportunities. McGraw Hill Construction reported that most construction companies that use prefabricated manufacturing have expedited their project timelines by 35%, as compared to traditional site-built projects.[69] The same report also found that nearly half of market actors surveyed said that the costs of materials and assembly were lower for modular homes.[70] An industry publication by the (pro-modular) Modular Building Institute also reported that modular construction results in less construction waste, a safer working environment, and shorter project

> "We try to do a project with 40 to 50 homes using two to three plans over and over. The factory saves money by increasing efficiency, we save money on building repetition, and can pass that on to the customer to make the housing more affordable."
>
> *– Modular Manufacturer*

[68] Home Guide. "Modular Home Prices 2021," https://homeguide.com/costs/modular-home-prices.
[69] McGraw Hill Construction. "Prefabrication and Modularization," 2011, https://www.nist.gov/system/files/documents/el/economics/Prefabrication-Modularization-in-the-Construction-Industry-SMR-2011R.pdf.
[70] McGraw Hill Construction. "Prefabrication and Modularization," 2011, https://www.nist.gov/system/files/documents/el/economics/Prefabrication-Modularization-in-the-Construction-Industry-SMR-2011R.pdf.

schedules, as compared to site-built projects.[71] One interviewee for this study estimated that modular homes cost about 10% less than comparable homes built with traditional site-built construction methods. Stakeholders noted that the high volume of customized projects in the single-family modular market (stakeholders estimated these projects are about 70% of the market) are a barrier to streamlined manufacturing processes and keep costs similar to traditional site-built construction.

Shipping and transportation challenges. One interviewee explained that manufacturers usually ship within a certain radius of the factory, typically about 500 miles, as shipping costs increase with distance. Interviewees noted that if a customer has a tight timeline, or there are labor shortages, they may be willing to pay higher transportation costs. Interviewees added that state laws governing modular home transportation can further increase costs by restricting mileage or hours of travel, mandating an escort vehicle, or requiring travel permits.

[71] Modular Building Institute. "2020 Permanent Modular Construction Report," May 2020, https://www.modular.org/documents/public/images/PDFs/MBI-PMC-annual-report-2020.pdf.

Section 8 Prefabricated Market Actors and Supply Chain

8.1 HUD Housing

Market actors. Key market actors in the HUD home industry include: buyers (owner-occupants, developers, or HUD home park owners with rental units); manufacturers; retailers or home dealers; park community owners; and third-party inspectors, responsible for ensuring compliance with the HUD code or ENERGY STAR.[72] The role of retailers and home dealers, as intermediaries between the buyer and manufacturer, is unique to this market. Stakeholders reported that retailers and home dealers typically offer a variety of models, including ENERGY STAR options, from a selection of manufacturers. Dealers can also assist in locating HUD home communities and installation sites.

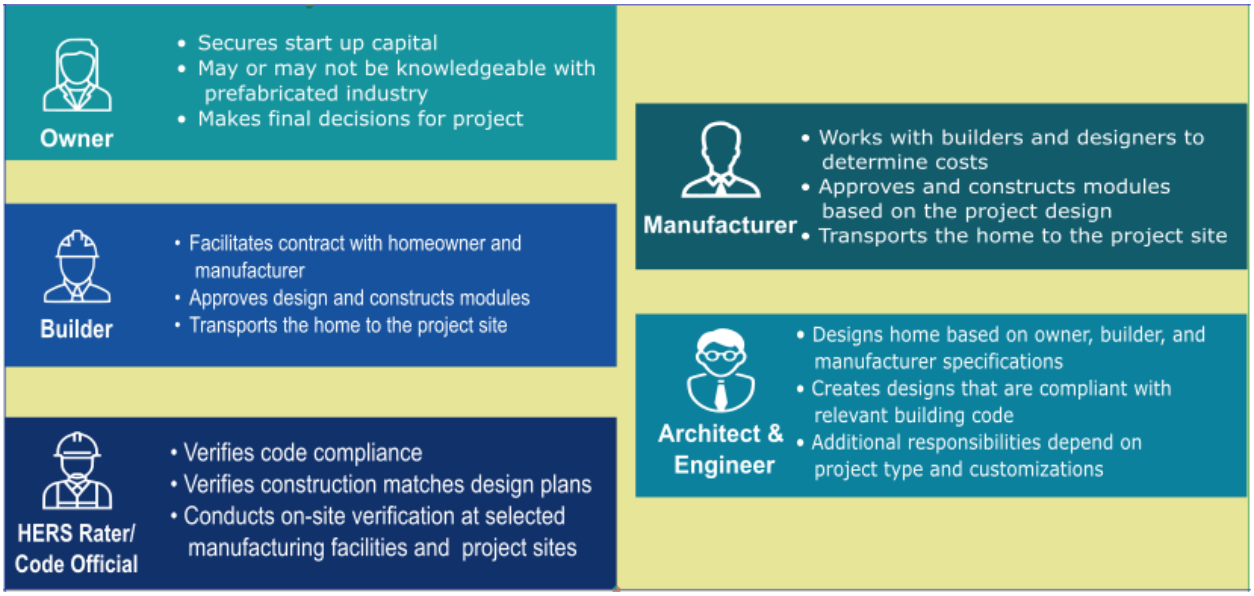
8.2 Modular Housing

Market actors. Key market actors in the modular industry include: buyers; developers; manufacturers, contractors and builders; designers, architects, and engineers; HERS raters; transportation companies; and on-site teams (set crew and equipment operators).[73] Typically, single-family prospective buyers work with builders and architects if necessary to discuss design layouts, project costs, and financing options. After making their selections, the buyer executes a contract with the builder who then commissions a manufacturer to construct the modules. Manufacturers can facilitate sales directly but will often work through a modular builder or general contractor. In the multifamily sector, developers may solicit preliminary designs and planning options from market actors such as architects, general contractors, and engineers, depending on the size and complexity of the project. Whether or not these players recommend modular options during early planning discussions can have a large impact on the eventual design decisions.

[72] Manufactured Housing Institute. "2021 Manufactured Housing Facts Industry Overview," https://www.manufacturedhousing.org/wp-content/uploads/2021/05/2021-MHI-Quick-Facts-updated-05-2021.pdf.
[73] A set crew is the on-site team that connects and installs the modules to create one continuous structure.

Figure 8 describes some of the key functions of various market actors in the modular industry. In contrast, HUD market actors align with a more traditional manufacturing process, with purchasers buying heavily regulated units with limited customization options.

Figure 8: Modular Home Market Actor Roles



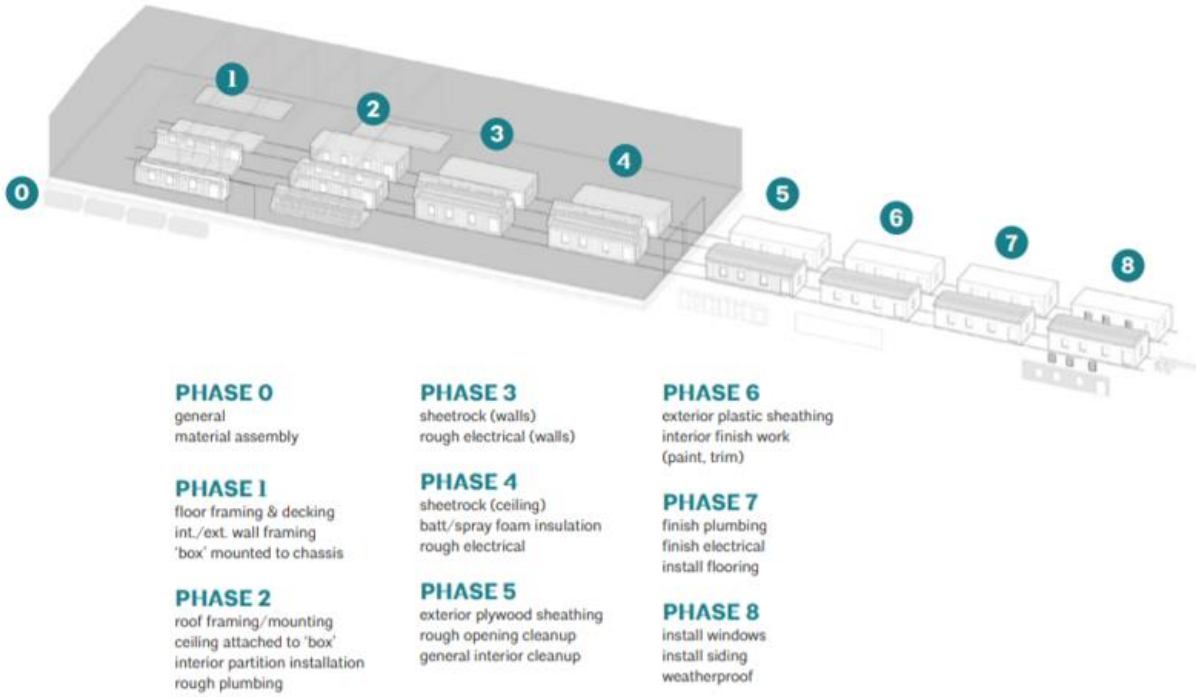
While there are currently no modular manufacturers operating in Massachusetts, the team estimates that 58 modular manufacturers ship homes to Massachusetts and 28 modular builders work in Massachusetts.[74]

Phased manufacturing. Modular homes are manufactured in multiple phases, and during each phase home are generally inspected for quality and safety by a HERS Rater, building inspector,

[74] Modular Building Institute. "MBI Member Profiles," https://www.modular.org/HtmlPage.aspx?name=mbi_members.

or the manufacturer's quality manager. Phased production can help ensure product consistency. Figure 9 provides an example of modular manufacturing phases.

Figure 9: Example of Modular Manufacturing Phases



Section 9 Energy Efficiency in Prefabricated Homes

9.1 HUD Housing

ENERGY STAR certified manufacturers. Manufacturers that produce ENERGY STAR certified HUD homes must meet a variety of requirements to attain and maintain certification. Requirements for such facilities include protocols such as hiring a trained Certifier, meeting measure-level requirements (e.g., wall insulation, air sealing, duct tightness), incorporating ENERGY STAR features into inspections, developing and following site installation checklists, inspecting/testing at least two percent of installed homes annually, submitting the ENERGY STAR partnership agreement, and so forth.[75] In turn, the EPA also certifies Quality Assurance Providers to provide overall QA/QC for the ENERGY STAR program, training certifiers and periodically inspecting work, much like RESNET certifies Providers to oversee the work of certified HERS raters.[76]

ENERGY STAR certified homes. HUD manufacturers have reported shipping more ENERGY STAR units each year. As of late 2020, ENERGY STAR certified homes accounted for 30% of HUD housing shipments in the United States and 37% of shipments into New England.[77] Massachusetts had the highest rate of ENERGY STAR certified HUD homes in New England – 80%. Table 8 shows quarterly shipment data through September 2020. As of May 31, 2020, HUD homes going through the ENERGY STAR program must comply with more stringent Version 2 requirements.[78] If the DOE incorporates higher efficiency energy requirements into the HUD code (i.e., based on the 2021 IECC), the ENERGY STAR requirements would likely be updated accordingly.

Table 8: ENERGY STAR HUD Homes, 2020 Shipments (Q1-Q3)

State	Total Units	ENERGY STAR	
		Units	% of Total
Connecticut	71	4	6%
Maine	403	118	29%
Massachusetts	69	55	80%
New Hampshire	238	86	36%
Rhode Island	26	5	19%
Vermont	88	61	69%

[75] ENERGY STAR. “New Construction Manufactured Homes Version 1,” June 2019, https://www.energystar.gov/sites/default/files/asset/document/Manufactured%20Homes%20Archived%20Webpages%20v2%202019-06-18.pdf?16f6-f81c#:~:text=To%20qualify%20as%20ENERGY%20STAR,space%20cooling%2C%20and%20water%20heating.
[76] RESNET. "Accredited Providers,” https://www.resnet.us/providers/accredited-providers/.
[77] Systems Building Research Alliance. “ENERGY STAR Certified Manufactured Homes,” https://www.research-alliance.org/ENERGY_STAR_Manufactured_Homes_Market_Share_Report.pdf.
[78] Systems Building Research Alliance . “ENERGY STAR Manufactured Homes Report,” https://www.research-alliance.org/ENERGY_STAR_Manufactured_Homes_Market_Share_Report.pdf.

> "A HUD home built in 2019 could be nearly the same as what was made in 1998."
>
> *– Implementor of HUD Homes Efficiency Program*

Four interviewees specifically described how support for the ENERGY STAR program from key stakeholders, including utilities and the federal government, had been critical to building ENERGY STAR market share, though it does add to a unit's upfront cost. Interviewees also confirmed that there was not a commercially available above-ENERGY STAR HUD product in the Northeast, and that a new standard would require federal approval and updates to inspection protocols, a barrier to significant (or quick) changes.

DOE considering 2021 IECC standards for HUD homes. The DOE has proposed an update to the HUD code that would significantly increase the energy efficiency of HUD homes.[79] The proposed updates are based on the 2021 IECC, with some adjustments largely designed to limit incremental costs. The proposal includes two options: a tiered option, with a lower and higher efficiency set of measure-level values (Tier 1 and Tier 2, respectively) and an un-tiered option meeting Tier 2 levels of performance. In the tiered approach, HUD homes retailed at $55,000 or less would only need to meet the less efficient Tier 1 standards–an attempt to keep upfront costs low. The proposal includes requirements for the building envelope, air and duct leakage, and duct insulation. There are no requirements for lighting, appliances, HVAC efficiency, and domestic hot water efficiency, all of which would be subject to typical federal minimum equipment standards. In anticipation of this potential change to the federal HUD code, the modeling in this study includes variations of the HUD prototype models that meet both the Tier 1 and Tier 2 proposed efficiency values.

Northwest Energy Efficiency Alliance's (NEEA) Manufactured Homes Program (NEEM+). NEEA helped develop the NEEM specification in the Northwest as part of a market transformation effort to improve the energy efficiency of HUD homes beyond ENERGY STAR levels, which essentially represent a performance improvement over an outdated set of performance requirements.[80] Now in its second version (called *ENERGY STAR with NEEM+*), the standard represents an above-ENERGY STAR level of performance and has QA/QC protocols much like the nationwide ENERGY STAR program. Three manufacturers in the Northwest are certified NEEM+ partners, though the program reports that over 75 utilities in the Northwest currently provide incentives for NEEM+ HUD homes.[81] Still, NEEM+ home sales represent only a fraction of the HUD home market in the Northwest, increasing from 28 units in 2018 to 42 in 2019 and 73 in 2020 (only about 4% of new HUD homes sold). NEEA's market transformation work via the NEEM program has included work to build the supply of NEEM+ homes (e.g., working with manufacturers to build the specifications into their factories) and drive demand for them (e.g.,

[79] Energy Department. Proposed rule 86 FR 47744, 08/26/2021. https://www.federalregister.gov/documents/2021/08/26/2021-17684/energy-conservation-program-energy-conservation-standards-for-manufactured-housing

[80] Apex Analytics, Submitted to NEEA. "Manufactured Homes Market Progress Evaluation #1," July 2020.

[81] NEEM Homes. "ENERGY STAR Manufactured Homes Utility Incentives List," April 2020, https://static1.squarespace.com/static/5b10a91989c172d4391ab016/t/5e8e3f31c8dadd101e99c810/1586380593987/Utilityincentives_2020+program+year.pdf.

trainings to help retailers sell them to customers). [82] A NEEM representative noted that they had pursued DOE funding to support transferring NEEM+ specifications to facilities in the Northeast, but had not been successful in obtaining such funding.[83]

Cost as a barrier to energy efficiency. As previously noted, HUD homes are typically sold through a retailer or dealer and customers select from a prescribed set of options, from aesthetic choices to energy efficiency, i.e., base HUD code or ENERGY STAR specifications. Limited options help keep costs of HUD homes low, a critical point for the HUD market, with an estimated 71% of HUD home occupants indicating affordability as a key driver to residing in a HUD home.[84] Interviewees also indicated that the low cost of HUD homes is one of the primary barriers to replacing HUD homes with modular homes. Additionally, HUD homes are generally not installed on owned land, meaning buyers may be less amenable to installing small modular homes in their place.

9.2 MODULAR HOUSING

Local codes, wide range of practices. As previously noted, modular homes must adhere to local energy code, regardless of where they are manufactured. That said, many manufacturers offer a range or tiered set of efficiency options, and some manufacturers only construct to a certain level, such as Zero-Net Energy.[85] One interviewed manufacturer, for example, reported that they only build homes that are ZNE and use the same building shell assemblies for every project and offer a small selection of high-efficiency electric HVAC options. Ultimately, all interviewees noted that the customer drives the efficiency of the project, either directly (e.g., direct request) or indirectly (e.g., selecting efficiency-minded contractors, setting the budget, etc.).

Modular home efficiency compared to site-built. Interviewees compared the efficiencies of modular and site-built homes. They generally described how high-performance standards such as Passive House or ZNE can be met via modular or site-built construction methods, but factory-environments can make the process easier or provide other benefits. Some cited advantages include the following:

- construction optimization (i.e., streamlined manufacturing processes and reduced waste)
- consistent, repeatable processes independent of staff turnover (including energy-efficiency practices)
- economies of scale
- climate-controlled building environment
- quality control throughout construction to ensure code compliance

[82] NEEA. "Manufactured Homes Market Progress Evaluation #1," July 2020, https://neea.org/img/documents/Manufactured-Homes-Market-Progress-Evaluation-1.pdf.
[83] Email between NMR staff and NEEM Program Customer Support, October 28, 2021.
[84] Manufactured Housing Institute, "2021 Manufactured Housing Facts Industry Overview," https://www.manufacturedhousing.org/wp-content/uploads/2021/05/2021-MHI-Quick-Facts-updated-05-2021.pdf.
[85] The teams secondary review found that modular manufacturers that built high performance homes are typically small and serve a small subset of the market, as there is still limited customer demand for extremely efficient homes.

- material selection (healthy material and embodied carbon considerations)

Interviewees also noted that modular construction typically has high levels of QA/QC built into the production process, though they are not without opportunities for system failure (e.g., during transportation, setting or connecting modules onto a foundation, or installing mechanical systems). Successful site-installation (particularly properly sealed module connections) is critical to avoid offsetting any efficiencies associated with factory construction methods.

Development of ZNE/PH design templates. Several interviewees discussed how modular manufacturers utilize building design templates, a set of repeatable construction practices that can be used as the building blocks for numerous design variants. Developing templates at ZNE or Passive House levels of efficiency represents a significant one-time cost, but once a factory finalizes new specifications, these practices can be replicated for limited incremental cost. This approach can help manufacturers meet customer demand for customized projects by standardizing building shell and HVAC systems while allowing flexibility with layouts and finishes and even overall layout of modules. Some manufacturers, however, may need or benefit from technical support in developing new templates.

Cost of ZNE efficiency variable but modest. NMR asked modular manufacturers about the cost of building modular homes to higher efficiency standards, such as to ZNE levels. Manufacturers noted that estimating incremental costs was challenging because modular homes are often highly customized and site-specific, and because manufacturers operate in different states with different efficiency baselines. Those caveats aside, one estimated doing so would add $10,000 to $20,000 to a project's cost, a second estimated the incremental cost at $10 to $15 dollars per square foot,[86] and another estimated it would add 3% to 10% to the home's cost.

Barriers for producing ZNE or extremely efficient homes. As with traditional construction, interviewees reported that most customers prioritize design, layout, or other amenities (e.g., attached garage or upgraded finishes) rather than efficiency. Interviewees cited additional barriers to produce extremely high-efficiency products, such as the need for technical assistance on developing design templates, the need for training on how to incorporate high-performance building techniques into factory processes, and an aversion to certifications such as Passive House due to certification, labor, and material costs. One manufacturer noted that pursuing Passive House certification is a potential barrier, but the industry would be open to incorporating Passive House techniques into designs and manufacturing processes, especially if incentives were available or manufacturers could get support in driving customer demand. Two manufacturers noted that major design changes can lead to costly manufacturing process adjustments, but the modular industry already deals with this challenge due to high demand for custom projects.

Examples of high-efficiency construction practices. Interviewees provided examples of how they and other manufacturers incorporate energy-efficient practices into their processes. One manufacturer described how they achieve ZNE performance through double-stud walls[87] with

[86] As context, this metric indicates a $15,000 to $30,000 incremental cost for a home in the 1,500 to 2,000 square foot range.
[87] The amount of materials used in a double-stud wall is more than a traditional 2x6 wall assembly which increases the overall material cost of the building.

dense-packed fiberglass and SIP panels for the roof, using both factory assembly and panelized components in one housing product. This manufacturer also described focusing on the health impacts of using low- and no-volatile organic compound (VOC) materials and the installation of indoor air quality monitors with ERV systems. Another manufacturer described how climate-controlled factory conditions allow for beneficial sequencing. For example, they described installing mechanical, electrical, and plumbing (MEP) systems before exterior sheathing, allowing them to cut fewer MEP-related holes in existing sheathing. In addition, they said they add exterior insulation, insulate double-stud walls with cellulose, and install triple pane windows, without weather concerns.

Some manufacturers may leave certain components such as ductwork or product installation (such as spray foam insulation) to site crews to ensure product specifications are met or to avoid challenges and damage from transportation. While some modular manufacturers may only offer one assembly-type for each home component, many appear able to actively customize building shell assemblies to meet project and customer needs.

Section 10 Savings Potential in the Prefabricated Homes Market

This section discusses results of the prototype energy modeling task and estimates the gross technical potential (GTP) savings under various program intervention scenarios. **All modeled consumption and savings are based on site energy savings.** Prototype model details are presented in Appendix D. The GTP estimates provide an upper-bound of gross technical savings that would be realized if the programs were to generate the modeled savings for all new prefabricated homes. Future research could estimate achievable or economic potential, which would be much lower and subject to the nature of any prefabricated program offerings by the PAs.

These estimates are not predictions. GTP estimates assume 1) all new prefabricated homes in Massachusetts participate in a PA offer, 2) homes follow the team's modeling assumptions and 3) achieve the levels of performance described in the modeling, and 4) the relative mix of electric and gas-heated homes follows the proportion seen in the most recent relevant baseline studies.

10.1 HUD Homes

As described in Appendix D, the study developed energy models for HUD homes at six performance levels. For each performance level, the team modeled an all-electric and a natural gas variant for 12 total HUD prototypes. These categories represent efficiency standards that a PA program might target for participant homes, and we include consumption and GTP estimates for each scenario. The six modeled categories include the following:

1. Baseline: ENERGY STAR Certified Manufactured Homes, Version 2
2. 2021 IECC Tier 1
3. 2021 IECC Tier 2
4. Northwest Energy Efficient Manufactured Housing Program (NEEM+)
5. NEEM High-Performance Manufactured Home Pilot program (HPMH)
6. PH/ZNE

10.1.1 Unit-level Consumption

Annual energy consumption of HUD home prototypes. Among the models of a given fuel (e.g., the all-electric models), all but the 2021 IECC Tier 1 HUD variant outperformed the Baseline ENERGY STAR model. The 2021 IECC Tier 1 models consumed a negligible amount more energy than their respective Baseline models but performed comparably. The all-electric prototypes (homes with heat pumps and electric resistance or HPWHs, as described in Appendix D) consume less site energy than their natural gas counterparts at each of the six assessed performance levels (e.g., Baseline, 2021 IECC Tier 1, etc.). The all-electric and natural gas prototypes have the same building envelope efficiency, lighting, and appliance end-uses for each of the assessed performance levels–only the mechanical systems differ.

Among the all-electric prototypes, energy consumption ranges from a 1% increase in the 2021 IECC Tier 1 variant to a 51% reduction in the PH/ZNE model, relative to the all-electric Baseline prototype (Table 9). Savings between the non-Baseline *all-electric* prototypes and the *gas* Baseline prototype are even higher, ranging between 32% for the 2021 IECC Tier 1 prototype and 67% for the PH/ZNE prototype.

For natural gas prototypes, energy consumption ranges from a 1% increase in the 2021 IECC Tier 1 variation to a 48% reduction in the PH/ZNE model relative to the gas Baseline (ES V2) prototype.

Table 9: HUD Prototypes Annual Consumption (MMBtu/Year)

Fuel	Unit-level Consumption										
	Baseline (ES V2)	2021 IECC Tier 1		2021 IECC Tier 2		NEEM+		HPMH		PH/ZNE	
	MMBtu/ Year	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)
All-electric prototypes											
Electric	46.6	47.1	-1%	35.4	24%	38.8	17%	28.5	39%	22.7	51%
Natural gas furnace with central AC and natural gas water heater prototypes											
Gas	53.8	54.8	-2%	43.6	19%	42.4	21%	37.3	31%	21.6	60%
Electric	15.4	15.4	--	14.9	3%	15.0	3%	14.7	5%	14.7	5%
Total	*69.2*	*70.2*	*-1%*	*58.5*	*15%*	*57.3*	*17%*	*52.0*	*25%*	*36.3*	*48%*

10.1.2 Unit-level Consumption by End-Use

Annual consumption by end-use. The all-electric models have substantially lower heating and water heating consumption than their natural gas counterparts (

Table 10). Only the natural gas PH/ZNE package compares favorably to the electric packages, in terms of heating consumption; it outperforms every all-electric variation below the PH/ZNE level. Otherwise, all of the natural gas models have higher heating consumption than even the *baseline* all-electric model. However, when summing heating and domestic hot water (DHW) consumption, the all-electric HPMH prototype still consumes less energy for these two end-uses than the PH/ZNE gas prototype, which has a much higher-performance (and more expensive) envelope. The lower consumption in the all-electric prototypes is driven by the increased efficiency of heat pumps compared to the gas furnace, and more efficient electric water heating options. To avoid focusing on appliance impacts, all prototype models are consistently modeled with electric appliances (i.e., no gas stoves or ovens).

Table 10: Annual Energy Consumption Results by End-Use for HUD Home Prototypes (MMBtu)

End-use	Fuel	Unit-level Consumption										
		Baseline (ES V2)	2021 IECC Tier 1		2021 IECC Tier 2		NEEM+		HPMH		PH/ZNE	
		MMBtu/Year	MMBtu/ Year	Savings (%)	MMBtu/ Year	Savings (%)	MMBtu/ Year	Savings (%)	MMBtu/ Year	Savings (%)	MMBtu/ Year	Savings (%)
All-electric prototypes												
Heating	Electric	24.3	24.8	-2%	13.2	46%	16.6	32%	12.9	47%	6.7	72%
Cooling		0.5	0.5	0%	0.3	40%	0.4	20%	0.2	60%	0.2	60%
DHW		8.5	8.5	0%	8.5	0%	8.5	0%	2.1	75%	1.8	79%
Lights/Appliances		13.3	13.3	0%	13.3	0%	13.3	0%	13.3	0%	13.9	-5%
Natural gas furnace with central AC and natural gas water heater prototypes												
Heating	Gas	39.7	40.7	-3%	31.8	20%	30.6	23%	26.0	35%	10.3	74%
	Electric	1.6	1.6	0%	1.2	25%	1.2	25%	1.0	38%	0.4	75%
Cooling	Electric	0.6	0.6	0%	0.4	33%	0.5	17%	0.4	33%	0.3	50%
DHW	Gas	14.1	14.1	0%	11.8	16%	11.8	16%	11.3	20%	11.3	20%
Lights/Appliances	Electric	13.3	13.3	0%	13.3	0%	13.3	0%	13.3	0%	13.9	-5%

10.1.3 Consumption and GTP

Estimated annual consumption and GTP for new HUD homes. If all new HUD homes in Massachusetts achieved performance comparable to the 2021 Tier 2 IECC and NEEM+ levels described in the prototypes, annual GTP savings would represent around 1,300 MMBtus, a 17% savings relative to Baseline (ES V2) levels of performance. If they achieved PH/ZNE levels, annual GTP would be nearly 4,000 MMBtus, a savings of 48% (

Table 11).

Table 11: HUD Market-level Consumption and GTP

Estimated HUD Market Size (n=114)[a]

Fuel	Market-level Consumption										
	Baseline (ES V2)	2021 IECC Tier 1		2021 IECC Tier 2		NEEM+		HPMH		PH/ZNE	
	MMBtu/ Year	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)	MMBtu/ Year	Savings vs Baseline (%)
All-electric prototypes											
Electric	744	752	-1%	565	24%	619	17%	455	39%	362	51%
Natural gas furnace with central AC and natural gas water heater prototypes											
Gas	5,275	5,373	-2%	4,275	19%	4,157	21%	3,657	31%	2,118	60%
Electric	1,510	1,510	0%	1,461	3%	1,471	3%	1,441	5%	1,441	5%
Subtotal	*6,784*	*6,882*	*-1%*	*5,735*	*15%*	*5,628*	*17%*	*5,098*	*25%*	*3,559*	*48%*
Total Market Consumption and Gross Technical Potential											
Gas	5,275	5,373	-2%	4,275	19%	4,157	21%	3,657	31%	2,118	60%
Electric	2,254	2,262	0%	2,026	10%	2,090	7%	1,896	16%	1,803	20%
Total	**7,528**	**7,634**	**-106 (-1%)**	6,300	**1,228 (16%)**	**6,247**	**1,281 (17%)**	**5,553**	**1,975 (26%)**	**3,921**	**3,607 (48%)**

[a] Market-level consumption estimates for the multifamily modular market segment are based on the 2020 market size values presented in Table 4.

The team did not have reliable data for new HUD homes in Massachusetts. The most reliable data with fuel-mix information report national figures and include existing homes (which estimate 50% of HUD/mobile homes are all-electric).[88] [89] However, the Residential Energy Consumption Survey (RECS) suggests that HUD homes in the Northeast are primarily heated by gas or oil.[90]

The team applied the relative gas and electric fuel mix from the 2019 RNC baseline study to the prototype-level results. These GTP results assume that 14% of the 114 HUD homes shipped to Massachusetts in 2020 were primarily heated with electricity and the remaining 86% used natural gas prototype results.

10.2 Single-Family Modular Homes

As described in Appendix D, the study included energy models for single-family modular homes at three performance levels. As with HUD homes, for each performance level, models included an all-electric and a natural gas variant, for 6 total single-family modular prototypes. The three modeled categories include the following:

1. Baseline: UDRH. Based on the user-defined reference home (UDRH) from the 2019 RNC baseline study.
2. Enhanced: RNC program. Based on program home averages. Uses the DOE's Zero Energy Ready Homes Program values in the absence of program data.[91]
3. Passive House/Zero-net Energy (PH/ZNE). Model values are based on minimum suggested values under Passive House Institute U.S. (PHIUS) 2021+ standards.[92,93]

10.2.1 Unit-level Consumption

Annual energy consumption of single-family modular prototypes. At each performance level (i.e., Baseline, Enhanced, and PH/ZNE), the all-electric prototypes (homes with heat pumps and HPWHs, as described in Appendix D) consume less site energy than their natural gas counterparts (Table 12). (The all-electric and natural gas prototypes have the same building envelope for each of the three assessed performance levels–only the mechanical systems differ.)

For all-electric prototypes, energy consumption is reduced by 5% in the Enhanced model and 32% in the PH/ZNE model, relative to the all-electric Baseline prototype. Savings between the all-electric Enhanced and PH/ZNE models and the gas Baseline prototype are even higher (51% and

[88] https://www.aceee.org/sites/default/files/publications/researchreports/a124.pdf
[89] https://www.eia.gov/consumption/residential/data/2015/hc/hc6.1.xlsx
[90] https://www.eia.gov/consumption/residential/data/2015/index.php?view=microdata
[91] U.S. Department Of Energy, "DOE Zero Energy Ready Home National Program Requirements (Rev. 07)," *energy.gov*, https://www.energy.gov/sites/default/files/2019/04/f62/DOE%20ZERH%20Specs%20Rev07.pdf.
[92] ZNE homes require at least some on-site renewable energy generation to technically be zero-energy. This prototype category does not include the renewable energy system required to bring the home to full ZNE, like the Department of Energy's Zero Energy Ready Home concept.
[93] Google Maps, "PHIUS Climate & 2021 Prescriptive Snapshot Map," Map. United States, https://www.google.com/maps/d/u/0/viewer?mid=1Gy69_ozJC1mG4sHZuURB5b33G_ERXFWS&ll=42.289737936994754%2C-71.64213724193927&z=11.

65%, respectively). For natural gas prototypes, the energy consumption is 6% lower in the Enhanced model and 48% lower in the PH/ZNE model relative to the gas Baseline prototype.

Table 12: Single-Family Modular Prototypes Annual Consumption (MMBtu/Year)

Fuel	Unit-level Consumption				
	Baseline	Enhanced		PH/ZNE	
	MMBtu/Year	MMBtu/Year	Savings vs Baseline (%)	MMBtu/Year	Savings vs Baseline (%)
All-electric prototypes					
Electric	50.8	48.4	5%	34.3	32%
Natural gas furnace with central AC and natural gas water heater prototypes					
Gas	74.6	68.9	8%	27.2	64%
Electric	24.7	24.5	1%	24.1	2%
Total	*99.3*	*93.4*	*6%*	*51.3*	*48%*

10.2.2 Unit-level Consumption by End-Use

Annual consumption by end-use. The all-electric models have substantially lower heating and water heating consumption than their natural gas counterparts (Table 13). The PH/ZNE natural gas prototype outperforms the all-electric Baseline and Enhanced prototypes, but otherwise the gas variants all have higher heating consumption than the all-electric models considered. However, when combining space heating and water heating consumption, the all-electric Enhanced prototype consumes less energy for these two end-uses than the PH/ZNE gas prototype, which has a much higher-performance envelope. The lower consumption in the all-electric prototypes is driven by the increased efficiency of heat pumps compared to the gas furnace and water heater. Note that all prototype models have electric appliances (i.e., no gas stoves or ovens).

Table 13: Annual Energy Consumption Results by End-Use for Single-Family Modular Prototypes (MMBtu)

End Use	Fuel	Unit-level Consumption				
		Baseline	Enhanced		PH/ZNE	
		MMBtu/Year	MMBtu/Year	Savings (%)	MMBtu/Year	Savings (%)
All-electric prototypes						
Heating	Electric	26.3	24.0	9%	9.0	66%
Cooling		0.3	0.3	--	0.4	-33%
DHW		2.7	2.6	4%	2.2	19%
Lights/Appliances		21.5	21.6	-0.5%	22.6	-5%
Natural gas furnace with central AC and natural gas water heater prototypes						
Heating	Gas	63.6	57.8	9%	16.3	74%
	Electric	2.5	2.3	8%	0.7	72%
Cooling	Electric	0.7	0.6	14%	0.8	-14%
DHW	Gas	11.0	11.0	--	10.8	2%
Lights/Appliances	Electric	21.5	21.6	-0.5%	22.6	-5%

10.2.3 Market-level Consumption and GTP

Estimated annual consumption and GTP for the newly constructed single-family modular market. If all new, single-family modular homes in Massachusetts achieved the Enhanced levels of performance described in the prototypes, annual GTP savings would represent around 3,300 MMBtus, a 6% savings relative to Baseline (UDRH) levels of performance (Table 14). If they achieved PH/ZNE levels, annual GTP would be approximately 26,800 MMBtus, a savings of 47%.

Table 14: Single-family Modular Market-level Consumption and GTP

Estimated Single-family Modular Market Size (n=615)[a]

Fuel	Market-level Consumption				
	Baseline	Enhanced		PH/ZNE	
	MMBtu/Year	MMBtu/Year	Savings vs Baseline	MMBtu/Year	Savings vs Baseline
All-electric prototypes					
Electric	4,373	4,166	5%	2,953	32%
Natural gas furnace with central AC and natural gas water heater prototypes					
Gas	39,448	36,434	8%	14,383	64%
Electric	13,061	12,956	1%	12,744	2%
Subtotal	*52,509*	*49,390*	*6%*	*27,127*	*48%*
Total Market Consumption and Gross Technical Potential					
Gas	39,448	36,434	3,014 (8%)	14,383	25,065 (64%)
Electric	17,434	17,122	312 (2%)	15,697	1,737 (10%)
Total	**56,882**	**53,556**	**3,326 (6%)**	**30,080**	**26,802 (47%)**

[a] Market-level consumption estimates for the single-family modular market segment are based on the 2020 market size values presented in Table 1.

To develop these estimates, we applied the saturation of homes from the 2019 RNC baseline study that were primarily heated with electricity (14%) to the estimated modular market size (i.e., 14% of 615 homes) to calculate total consumption and GTP for all-electric homes, with the remaining 86% of the market using the natural gas prototype results.

10.3 Multifamily Modular Homes

10.3.1 Unit-level Consumption

Annual energy consumption of multifamily modular prototypes. Table 15 presents the annual consumption for the multifamily modular prototypes. The team modeled both end-unit and interior-unit multifamily prototypes, and the unit-level results below are weighted based on the proportion of end and interior units that would likely occur in a two-story, 20-unit building.[94]

[94] We assume that for a hypothetical 20-unit, two-story multifamily building, eight (40%) of the units would be end-unit homes, and 12 (60%) would be interior units, and weighted consumption accordingly. Results for end-unit and interior-unit prototypes are discussed at the end-use level.

As with the single-family prototypes, each all-electric multifamily modular model has lower total site energy consumption than its natural gas counterpart (a prototype with the same building shell). For the all-electric prototypes, the Enhanced model has 10% lower consumption than the all-electric Baseline model; the all-electric PH/ZNE's consumption is 41% lower. Savings are higher still for the all-electric Enhanced and PH/ZNE models when compared to the *natural gas* Baseline model (34% and 57%, respectively). Among the natural gas prototypes, the Enhanced model uses 5% less energy than the Baseline version; the PH/ZNE model uses 39% less.

Table 15: Multifamily Modular Prototypes Annual Consumption (MMBtu)

Fuel	Unit-level Consumption				
	Baseline	Enhanced		PH/ZNE	
	MMBtu/Year	MMBtu/Year	Savings vs Baseline (%)	MMBtu/Year	Savings vs Baseline(%)
All-electric prototypes					
Electric	40.4	36.2	10%	23.8	41%
Natural gas furnace with central AC and natural gas water heater prototypes					
Gas	37.7	34.9	8%	15.8	58%
Electric	17.1	17.0	1%	17.4	-2%
Total	*54.9*	*51.9*	5%	*33.3*	39%

10.3.2 Unit-level Consumption by End-Use

The following subsections describe the end-use consumption for end-unit and interior-unit models. Generally, the consumption by end-use is the same or slightly higher in the end-unit prototypes compared to interior-units, except for the PH/ZNE models, which exhibit lower heating consumption than the interior prototypes (likely due to solar gain for end units).

10.3.2.1 End-Unit Consumption by End-Use

Annual consumption by end-use. Table 16 presents the annual energy consumption by end-use for the multifamily modular end-unit prototypes. As with the single-family prototypes, the all-electric models have lower heating and water heating end-use consumption than their natural gas prototype counterparts, which have the same building shell. The all-electric Baseline and Enhanced prototype models include electric resistance tanks rather than HPWHs, which drives DHW consumption closer to levels seen in the gas prototypes. Note that all prototype models have electric appliances (i.e., no gas stoves or ovens).

Table 16: Annual Energy Consumption Results by End-Use for Multifamily Modular End-Unit Prototypes (MMBtu)

		Unit-level Consumption				
		Baseline	Enhanced		PH/ZNE	
End Use	Fuel	MMBtu/Year	MMBtu/Year	Savings (%)	MMBtu/Year	Savings (%)
All-electric prototypes						
Heating	Electric	15.6	11.1	29%	4.2	73%
Cooling		0.4	0.3	25%	0.2	50%
DHW		10.5	10.5	0%	2.2	79%
Lights/Appliances		15.5	15.5	0%	16.8	-8%
Natural gas furnace with central AC and natural gas water heater prototypes						
Heating	Gas	29.4	26.2	11%	4.6	84%
	Electric	1.1	1	9%	0.2	82%
Cooling	Electric	0.5	0.4	20%	0.4	20%
DHW	Gas	11.3	11.5	-2%	10.8	4%
Lights/Appliances	Electric	15.5	15.5	0%	16.8	-8%

10.3.2.2 Interior-Unit Consumption by End-Use

Annual energy consumption by end-use. Table 17 presents the annual energy consumption by end-use for the multifamily modular interior-unit prototypes. The consumption by end-use followed similar trends as the end-unit prototypes, with all-electric models consuming less energy related to heating and water heating than their gas counterparts.

To limit the prototype modeling effort, the interior-unit gas prototype consumption used the results from both the all-electric interior-unit and end-unit gas prototypes. Heating consumption is estimated by taking the ratio between the all-electric interior-unit and end-unit heating consumption and multiplying by the end-unit gas prototype heating consumption. For DHW, cooling, and electrical heat consumption end-uses, the gas and electric consumption was assumed to be the same as the end-unit consumption. For lights and appliance consumption, we applied the same consumption values from the interior-unit lights and appliances.

Table 17: Annual Energy Consumption Results by End-Use for Multifamily Modular Interior-Unit Prototypes (MMBtu)

End Use	Fuel	Unit-level Consumption				
		Baseline	Enhanced		PH/ZNE	
		MMBtu/Year	MMBtu/Year	Savings (%)	MMBtu/Year	Savings (%)
All-electric prototypes						
Heating	Electric	13.0	9.1	30%	4.8	63%
Cooling		0.3	0.3	17%	0.2	50%
DHW		10.5	10.5	0%	2.2	79%
Lights/Appliances		15.5	15.5	0%	16.8	-8%
Natural gas furnace with central AC and natural gas water heater prototypes						
Heating	Gas	24.5	21.6	12%	5.3	78%
	Electric	1.1	1.0	9%	0.2	84%
Cooling	Electric	0.5	0.4	8%	0.4	11%
DHW	Gas	11.3	11.5	-2%	10.8	4%
Lights/Appliances	Electric	15.5	15.5	0%	16.8	-8%

10.3.3 Market-level Consumption and GTP

Estimated annual consumption and GTP for the newly constructed multifamily modular market. If all new, multifamily modular homes in Massachusetts achieved the Enhanced levels of performance described in the prototypes, annual GTP savings would represent around 1,700 MMBtus, a 6% savings relative to Baseline levels of performance (Table 18). If they achieved PH/ZNE levels, annual GTP would be approximately 12,100 MMBtus, a savings of 39%.

Table 18: Multifamily Modular Market-level Consumption and GTP

Estimated Multifamily Modular Market Size (n=568 units)[a]

Fuel	Market-level Consumption				
	Baseline	Enhanced		PH/ZNE	
	MMBtu/Year	MMBtu/Year	Savings vs Baseline	MMBtu/Year	Savings vs Baseline
All-electric prototypes					
Electric	1,379	1,236	10%	812	41%
Natural gas furnace with central AC and natural gas water heater prototypes					
Gas	20,128	18,612	8%	8,444	58%
Electric	9,149	9,074	1%	9,297	-2%
Subtotal	*29,277*	*27,686*	*5%*	*17,741*	*39%*
Total Market Consumption and Gross Technical Potential					
Gas	20,128	18,612	1,516 (8%)	8,444	11,685 (58%)
Electric	10,528	10,310	217 (2%)	10,109	419 (4%)
Total	***30,656***	**28,922**	**1,734 (6%)**	**18,553**	**12,103 (39%)**

[a] Market-level consumption estimates for the multifamily modular market segment are based on the 2020 market size values presented in Table 1.

To develop market-level GTP estimates for multifamily modular homes, we applied the saturation of units from the 20R30 RNC low-rise multifamily baseline study that were primarily heated with electricity (6%) to the estimated modular market size (i.e., 6% of 568 units) to calculate total consumption and GTP for all-electric homes, with the remaining 94% using the natural gas prototype results.

Gas savings opportunities (based on estimated GTP) appear greater due to the higher consumption of the baseline gas prototype and the prevalence of gas equipment in new homes, even though the all-electric prototypes have greater mechanical equipment efficiencies.

Appendix A Prefabricated Supply Chain Actors in the Northeast

Table 19 provides a list of all resident-owned manufactured (HUD and mobile) home communities in Massachusetts.[95] In these communities, residents own the land or a share of the land on which their homes are located, in contrast to communities where the homes sit on leased land.

Table 19: Resident-Owned Manufactured Home Communities in Massachusetts

Region	Name	City	Number of Lots
Cape	Harborside Village	Wellfleet	85
Central	Winbrook Acres Cooperative Corp	Auburn	102
	Wagon Wheel Cooperative Corp	Brookfield	144
	Nantomqua Cooperative Corp		85
	Quaboag Valley Co-Op	Palmer	92
	Sturbridge Retirement Co-op	Sturbridge	170
	Quabbin Sunrise Cooperative	Ware	65
	Evergreen Co-Op	Warren	23
	Heritage Association		91
Northeast	Family Estates Cooperative	Peabody	39
	Haven Circle Cooperative		39
	Oak Ledge Heights Co-Op		40
	Red Hill Cooperative, Inc.		25
	Whispering Meadows Cooperative		70
	Heritage Park Homeowners Coop	Salisbury	67
	Wayside Village	Shirley	64
Southeast	Cranberry Village	Carver	279
	South Meadow Village		522
	Pine Tree Village		186
	Halifax Estates	Halifax	430
	Conifer Green	Kingston	75
	Town and Country		212
	Twin Coach Estates Homeowners Association Inc.	Lakeville	64
	Edgeway Homeowner's Association Inc.	Middleborough	52
	Hillcrest Estates		97

[95] VEIC. "Zero Energy Modular Affordable Housing Initiative," February 2019.

	Rustic Pines Estates	North Attleborough	40
	Wamsutta Mobile Co-Op Home Village		84
	Norton Estates Co-op Corp	Norton	124
	Park Place	Peabody	50
	Plymouth Commons Co-op Corp	Plymouth	75
	Plymouth Mobile Estates Co-Op Corp		204
	West Wood Village		66
	Boston Road Mobile Home Park Tenants Association	Springfield	310
	Colonial Estates HOA	Taunton	148
	Oak Hill Manufactured Home Community		252
	Holly Heights Cooperative, Inc	West Wareham	44
	Turnpike Park Cooperative	Westborough	50
Western	Greenfield Country Estates Corp	Greenfield	66
	Bissinville Estates	Hinsdale	30
	Wheel Estates	North Adams	200
	Brookside Residents Association	Orange	44

Table 20 identifies the HUD home manufacturers in the Northeast.[96] All of these manufacturers are certified to produce ENERGY STAR homes.

Table 20: Manufacturers of HUD Homes in the Northeast

Company	Headquarters
Champion Home Builders	Claysburg, PA Ephrata, PA Sangerfield, NY
Clayton Homes	Lewistown, PA Bloomsburg, PA Paradise, PA
Colony Factory Crafted Homes	Shippenville, PA
Commodore Homes	Shippenville, PA
Eagle River Homes	Leola, PA
Ritz-Craft Corporation	Mifflinburg, PA
Pine Grove Manufactured Homes	Pine Grove. PA
Skyline Homes	Leola, PA

[96] The team reviewed a variety of online resources and manufacturer directories, including but not limited to the Systems Building Research Alliance (https://www.research-alliance.org/pages/es_plant_list.htm).

Table 21 presents selected modular manufacturers that appear to manufacture and deliver homes to Massachusetts.[97] This list is likely not exhaustive, as some manufacturers may be willing to ship into Massachusetts even if that is not their typical practice.

Table 21: Modular Home Manufacturers that Ship to Massachusetts

Company	Headquarters
Apex Homes	Middleburg, PA
ANC Modular Inc	Brantford, Ontario, Canada
Arning Companies	Cassville, MO
Art's-Wat Scientific, Inc	Monona, IA
B&T Manufacturing	Blackhawk, SD
Best GEN Modular	Rapid City, SD
Blox LLC	Birmingham, AL
BMarko Structures, LLC	Atlanta, GA
Britten Inc	Traverse City, MI
BROAD U.S.A. Inc	Hackensack, NJ
C&B Custom Modular Inc.	Bristol, IN
CC915, Inc	El Paso, TX
Champion Homes	Claysburg, PA
Chelsea Modular Homes	New Paltz, NY
Commodore Homes	Clarion, PA
Colony Factory Homes	Shippenville, PA
Corner Cast Construction Inc.	Montreal, Quebec, Canada
Crest Homes	Milton, PA
Custom Building Systems, LLC.	Middleburg, PA
DeLuxe Building	Middleburg, PA
Eagle Associates	Greenville, RI
Excel Homes	Liverpool, PA
Factory Direct Modular Homes	Brick, NJ
Falcon Structures	Manor, TX
Fleetwood Enterprises	Riverside, CA
Fuller Modular Homes	Suffield, CT
Hallmark Homes	Charlestown, RI
HHI Corporation	Ogden, UT
Huntington Homes	Montpelier, VT
Hunter Modular Construction	Jonesburg, MO
Icon Legacy Custom	Selinsgrove, PA
KBS Building Systems	South Paris, ME
Ikoniq	Canandaigua, NY
Integrity Building Systems	Milton, PA
IteraSpace	New Paris, IN

[97] The team reviewed a variety of online resources and manufacturer directories, including but not limited to the Modular Building Institute (https://www.modular.org/HtmlPage.aspx?name=mbi_members) and Modular Today (https://www.modulartoday.com/MA.html).

KBS Building Systems	South Paris, ME
Manorwood Homes	Pine Grove, PA
Modlogiq Inc.	New Holland, PA
Modular Connections, LLC	Bessemer, AL
Modern Building System, Inc.	Aumsville, OR
Modular USA Corporation	Aventura, FL
MSI of PA	Selinsgrove, PA
Muncy Homes	Muncy, PA
New Era Building Systems	Strattanville, PA
Parkline, Inc.	Eleanor, WV
Pennwest Homes	Emlenton, PA
Praxis Modular	New York, NY
Preferred Building Systems	Claremont, NH
RISE Modular	Minneapolis, MN
Ritz-Craft Corporation	Mifflinburg, PA
Sea Box, Inc	East Riverton, NJ
Signature Building Systems	Moosic, PA
Steel River Building Systems, Inc.	Pottstown, PA
Steelblox	Newbury Park, CA
Structural Modulars	Strattanville, PA
Sunbelt Modular	Phoenix, AZ
Westchester Modular Homes	Wingdale, NY
Z Modular	Chicago, IL
Zarrilli Homes LLC	Brick, NJ

Table 22 presents estimated pricing by builder for modular homes in Massachusetts, based on published data on their websites. Like the list of manufacturers previously, this list is likely not exhaustive.[98]

Table 22: Modular Home Builders in Massachusetts

Company	Headquarters	Pricing (Per Sq. Ft.)[1]
Acorn Desk House Company (panelized manufacturer)	Acton, MA	$285 - $420
All American Modular	East Falmouth, MA	$300 - $500
Allied Homes LLC Modular Homes	Barnstable, MA	$280 - $385
Atrium Custom Homes	Winchester, MA	--
Beaman Land & Home Sales	Winchester, MA	--
CapeBuilt Development	Amesbury, MA	--
CRM Modular	Douglas, MA	--
Custom Modular Homes USA	Newton, MA	--
DG Modular Homes	Boston, MA	--

[98] The team reviewed a variety of online resources and manufacturer directories, including but not limited to the Modular Building Institute (https://www.modular.org/HtmlPage.aspx?name=mbi_members).

Dreamline Modular	Lexington, MA	$300+
East Coast Homes	Somerset, MA	--
GBL Avis	Douglas, MA	$200 -$250
George Modular Homes	Newton, MA	$160+
Go Modular Homes	Shrewsbury, MA	--
Heritage Modular Homes	Newton, MA	$160 - $275
Huntington Homes	Sudbury, MA	--
Lindal Cedar Homes	Walpole, MA	$200 - $300
Mod Tech Homes LLC	Hingham, MA	--
Montgomery Modular Homes	Belchertown, MA	$300+
Moulton Real Estate & Construction	Ashburnham, MA	$160- $275
N.E Home Planning Center	Auburn, MA	--
Old Harbor Homes	North Chatham, MA	$155 - $300
Pioneer Modular Homes	Sturbridge, MA	$200 - $ 250
Pro-Mod Homes LLC	Pocasset, MA	--
Savoie Modular Homes	Boylston, MA	$180 - $290
Southeastern Development LLC.	Marion, MA	$250+
Sterling Home Development Corp	Woburn, MA	$250 - $350
The Home Store	Whately, MA	$155 - $300

[1] Range in price is based on available information from company websites.

Table 23 identifies manufacturers in the Northeast that produce panelized home components or design panelized homes. Panelized components can be used to construct an entire building shell or one facet of the building shell—with traditional site-built techniques used for the rest of structure.[99] This list may not be exhaustive, but this market is smaller than that of modular builders.

Table 23: Panelized Home Manufacturers in the Northeast

Company	Headquarters	Pricing (per sq. ft)
Davis Frame Co.	Claremont, NH	$350 - $550
Ecocor	Searsmont, ME	$325 - $450
Resolution: 4 Architecture	New York, NY	$250 - $425

Table 24 lists manufacturers of CrossMod homes.[100]

[99] The team reviewed a variety of online resources and manufacturer directories, including but not limited to the Modular Building Institute (https://www.modular.org/HtmlPage.aspx?name=mbi_members).
[100] Clayton Homes. "CrossMod Homes," accessed October 2021, https://www.claytonhomes.com/crossmod?utm_source=MNR&utm_medium=PR&utm_campaign=CrossMod2020&source=PR_MNR_CrossMod2020.

Table 24: Manufacturers of CrossMod Homes

JCompany	Headquarters
Adventure Homes	Garrett, IN
Cavco Industries, Inc	Phoenix, AZ
Clayton Homes, Inc.	Maryville, TN
Eagle River Homes, LLC	Leola PA
Kabco Builders, Inc.	Boaz, AL
Oak Creek Homes, LLC	Lancaster, TX
Pine Grove Homes	Pine Grove, PA
Skyline Champion Corporation	Troy, MI

Appendix B Prefabricated Home Programs

The following section describes select national and regional programs that seek to influence the prefabricated housing market, most of which target HUD homes.

HOME Investment Partnerships Program

The HOME Investment Partnerships Program (HOME) is the largest federal block grant in Massachusetts designed to help fund affordable housing projects.[101] HOME funds affordable housing programs including community development, neighborhood stabilization programs, and HUD housing improvements. HOME ensures that newly constructed HUD homes are certified to ENERGY STAR levels of efficiency. HOME tracks new HUD units in participating jurisdictions and identifies how many units are ENERGY STAR certified.[102] All HUD units are inspected by a Home Energy System Rater (HERS Rater) to ensure that they meet the energy-efficiency guidelines set by the U.S Environmental Protection Agency (EPA).

Vermont Mobile Home Replacement Program

Efficiency Vermont and Vermont Housing and Conservation Board (VHCB) launched a pilot version of this program in 2012.[103] The program replaces existing mobile homes with Zero Energy Modular Homes. Efficiency Vermont works with local modular manufacturers for this program. VERMOD is one of the manufacturers in charge of the replacement program. The program offers additional incentives for buyers below 80% of the median income and financing options.

Vermont Energy Investment Corporation (VEIC) launched a similar mobile home replacement program in Massachusetts, designed to shift people away from inefficient HUD homes into higher performance modular homes. In 2018, VEIC was awarded $1.05 million dollars to help implement the Zero Energy Modular Affordable Housing Initiative (ZE-MAHI) program into Massachusetts.[104] The goal of the program is to install ten affordable ZNE homes in Massachusetts. The units will replace HUD homes. ZE-MAHI provides resources and grants to potential home buyers to purchase an energy efficient home. ZE-MAHI provides support to homebuyers during the construction process and ensures that they receive all eligible incentives.[105] As noted, however, this represents a challenging proposition, as most HUD homes are not installed on fully owned land, making the financing and value proposition of installing modular homes in place of a HUD home less clear.

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[101] HUD Exchange. “HOME Overview,” https://www.hudexchange.info/programs/home/home-overview.
[102] HUD Exchange. “HOME ES Reports,” https://www.hudexchange.info/programs/home/home-energy-star-unit-reports/?filter_DateYearEach=2021&filter_Sort=&program=HOME&group=ES.
[103] VEIC, “Market Analysis for Net Zero Manufactured Home Replacements Delaware,” Jan 2015.
[104] Commonwealth of Massachusetts. “Baker-Polito Administration Announces $1 Million Grant to Increase Energy Efficiency in Modular Homes,” April 17, 2018. https://www.mass.gov/news/baker-polito-administration-announces-1-million-grant-to-increase-energy-efficiency-in-modular.
[105] Commonwealth of Massachusetts. “Zero Energy Modular Affordable Housing Initiative,” https://www.mass.gov/service-details/zero-energy-modular-affordable-housing-initiative.

ENERGY TRUST OF OREGON MANUFACTURED HOME REPLACEMENT PILOT

Energy Trust of Oregon (ETO) launched a HUD home replacement pilot in June of 2017 with the goal of offering financial and additional support to HUD homeowners. Currently 10% of Oregon's total residential building stock are HUD homes with 65% of those homes built before 1995.[106] ETO is replacing pre-1995 HUD homes with NEEM+ versions. ETO offers incentives up to $15,000 to participants and helped connect participants with HUD home retailers. ETO reported some logistical challenges in that newer HUD homes were larger than those constructed pre-1995, limiting the sites where they would serve as direct replacements. ETO reported 29 participants in 2020.

NEW YORK MOBILE & MANUFACTURED HOME REPLACEMENT PROGRAM (MMHR)

New York also launched a mobile/HUD home replacement program in 2020, funded by the New York State Homes and Community Renewal (HCR) and the New York State Tax Department. The program received a grant of $3.7 million to help assists low-income homeowners to help replace their old mobile and HUD home with a new HUD, modular or site-built home.[107] This program could serve a substantial market, as New York has over 84,000 HUD homes in 1,800 HUD/mobile home parks.

This program is available to low to moderate income HUD homeowners. The program also provides financial support for demolition and relocation.[108]

MAINE STATE HOUSING AUTHORITY PRE-1976 MOBILE HOME REPLACEMENT INITIATIVE.

The Maine State Housing Authority (Maine Housing) offers homeowners grants up to $35,000 to help replace their pre-1976 mobile homes with new ENERGY STAR HUD homes. The new home must be purchased through a licensed Maine dealer and be located on the site of the removed home.[109]

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[106] Opinion Dynamics. "Manufactured Home Replacement Pilot," Submitted to *The Energy Trust of Oregon*, August 12, 2020, https://www.energytrust.org/wp-content/uploads/2021/05/Manufactured-Home-Replacement-Pilot-Evaluation_Final-.pdf.
[107] Multi-Housing News. "New York Announces Grants for MHC," https://www.multihousingnews.com/post/governor-cuomo-announces-grants-for-mhc/.
[108] New York State Homes and Community Renewal. "Mobile and Manufactured Home Replacement Program (MMHR)," https://hcr.ny.gov/mobile-manufactured-home-replacement-program-mmhr.
[109] Maine State Housing Authority. "Pre-1976 Mobile Home Replacement Initiative," https://www.mainehousing.org/programs-services/homebuyer/homebuyerdetail/pre1976-mobile-home-replacement-initiative.

Appendix C References

This appendix compiles links to various websites and other program materials that NMR reviewed as part of this literature review and report. The sections below follow the sequence in the body of the report.

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Appendix D Prototype Energy Model Details

To estimate savings potential for a program offer, the study included prototype energy modeling for modular and HUD homes. The energy modeling effort included four core design templates: one HUD home, one single-family modular home, and two modular multifamily units—one end-unit and one-interior unit. Table 25 describes the general characteristics of each prototype energy model, informed by the literature review and for modular homes, typical values seen in the most recent RNC baseline study and federal guidelines.[110,111] Behavioral characteristics, such as thermostat setpoints, were kept constant across models.

Three of the four core design templates included two separate HVAC and DHW scenarios (i.e., all-electric and natural gas equipment). For those three design templates, all efficiency variations were modeled under both fuel scenarios.

For modular home prototypes, the team leveraged recent market data to determine common heating and hot water systems (i.e., natural gas furnaces and instantaneous water heaters) that are installed in the RNC market, and included all-electric variants given their inclusion in future programmatic efforts targeted at the RNC market. For HUD homes, the team did not have data on the saturation of mechanical equipment commonly installed in HUD homes. We leveraged the literature review and secondary data such as the ENERGY STAR equipment specifications to determine likely equipment scenarios for HUD homes. A second phase of this study could investigate alternative scenarios.

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Table 25: Modeling Characteristics for Prototype Homes

Characteristic	Modular Single-Family	Modular Multifamily	HUD
Housing type	Detached single-family	End-unit; interior-unit	HUD home
Bedrooms	3	2	2
Climate location	Worcester	Worcester	Worcester
Size (CFA)	2,775	1,200	960
Stories above-grade	2	2 (20-unit building)	1
Wall height (ft)	9.5	10	7.5
Ceiling	Flat	Flat	Flat
Foundation	Conditioned basement	Slab on-grade	Open-crawl space
Glazing area (split evenly in four directions)	225 ft^2	End unit: 135 ft^2; Interior unit: 90 ft^2	12% of wall area
HVAC scenarios	All-electric and nat. gas equipment	End unit: all-electric and nat. gas equipment Interior unit: all-electric only	All-electric and nat. gas equipment

HUD Home Prototype Models

Table 26 includes the measure-level efficiency values for the HUD home prototype energy models. The most efficient values for each set of measures are identified in blue. The efficiency scenarios are based on the six performance tiers listed below:

1. Baseline: ENERGY STAR Certified Manufactured Homes, Version 2. While the legal baseline for HUD homes may be the HUD code, the literature review suggested that most new HUD homes in Massachusetts are built to ENERGY STAR levels. [112,113] It should be noted that the ENERGY STAR electric heat pump package has lower minimum efficiency specifications for the wall (R-11), floor (R-22), and ceiling (R-33) compared to the ENERGY STAR high-efficiency furnace package minimum shell requirements. The team applied the same shell efficiency values for both the gas furnace and all-electric prototype models to maintain consistency between the prototypes. However, this means that savings for the all-electric HUD prototypes are conservative.
2. 2021 IECC Tier 1 proposed update, a lower efficiency option to keep upfront costs low.
3. 2021 IECC Tier 2 proposed update, a higher-efficiency option, and the proposed update

[112] ENERGY STAR. "National Program Requirements ENERGY STAR Certified Manufactured Homes, Version 2," *energystar.gov*, last modified July 01, 2019, https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Manufactured%20Homes%20National%20Program%20Requirements%20Version%202.pdf.

[113] ENERGY STAR, "Cost & Savings Estimates, ENERGY STAR Certified Manufactured Homes, Version 2," July 2020, https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Manufactured%20Homes%20Version%202%20Cost%20Savings%20Summary.pdf.

in absence of the tiered-structure.

4. Enhanced: Northwest Energy Efficient Manufactured Housing Program (NEEM+), a higher standard than ENERGY STAR.[114]
5. HPMH: NEEM High-Performance Manufactured Home (HPMH) Pilot program, a high-performance standard, given no official ZNE/PH standard for HUD homes.[115]
6. Highest: PH/ZNE, a variation that leverages the highest level of performance efficiency values from the single-family modular prototype. The team notes that the efficiency levels used in this variation may not all be physically or financially feasible for HUD homes to achieve.

[114]NEEM, "Technical Specification Comparison Between NEEM ver. 1.1 and ver. 2.0" *neemhomes.com*, last modified February 2019. https://static1.squarespace.com/static/5b10a91989c172d4391ab016/t/5c58dbc28165f5be9d9e8503/1549327298845/NEEM_Spec_Comparison_020419.pdf.

[115] Building America Partnership for Improved Residential Construction, "Northwest Energy Efficient Manufactured Housing Program High-Performance Test Homes," submitted to U.S. Department of Energy, September 2015, https://www.nrel.gov/docs/fy15osti/63894.pdf.

Table 26: Efficiency Values for HUD Home Prototype Energy Models

Component	Baseline (ENERGY STAR V2)	Tier 1 – 2021 IECC update[b]	Enhanced (NEEM+)	Tier 2 – 2021 IECC update[b]	HPMH	Passive House levels[c]
Above grade wall R-value (conditioned to ambient)	13 (16" OC)	19	21 (24" OC, insulated headers)	20+5	21 cavity (24" OC) + 5 continuous	46
Floor R-value (open crawl space)	30	22	33	30	38	49
Ceiling R-value (flat attic)	38	22	44	38	49	77
Window U-factor	0.35		0.25	0.30	0.22	0.16
Window SHGC	0.34	N/A (0.34)[a]	0.34	N/A (0.34)	0.28	0.26[a]
Duct LTO	6.0	4.0	6.0	4.0 (ducted), 0 (Ductless)[d]	4.0[a] (ducted), 0 (ductless)[d]	0[d]
Air infiltration (ACH50)	5.0		4.0	5.0	4.0	0.6
Duct insulation R-value (all locations)	8.0					
Lighting and Appliances	100% LED and ES appliances (all electric)[e]					
Ventilation	Exhaust only					ERV, 0.79 SRE
Natural gas furnace with central AC and gas water heater prototypes						
Cooling (SEER)	Central AC (13)[a]		Central AC (14)[a]		Central AC (15)[a]	
Heating (AFUE)	Furnace (95)				Furnace (97)[a]	
Water heater (EF)	30-gallon gas tank (0.62)[a]		30-gallon gas tank (0.70)[a]		30-gallon gas tank (0.72)[a]	
All-electric prototypes						
Cooling (SEER)	ASHP (14)		ASHP (15)[a]	MSHP (18)[a]		MSHP (20.0)
Heating (HSPF)	ASHP (8.2) w/resistance back-up		ASHP (9.2)[a] w/resistance back-up	MSHP (10.9)[a] w/resistance back-up		MSHP (12.0) w/resistance back-up[a]
Water heater (EF)	Storage tank (0.93)[a]				HPWH (3.50)[a]	HPWH (4.00)[a]

[a] Evaluation team assumption due to limited available market or program data.
[b] Proposed updates to the HUD code efficiency specifications for climate zone 3.
[c] PHIUS 2021+ prescriptive specifications for Worcester, MA.
[d] Duct system within thermal boundary; no duct leakage.

SINGLE-FAMILY MODULAR PROTOTYPE MODELS

Table 27 describes the efficiency values for the three single-family modular home model variants. The most efficient values for each set of measures are identified in blue. The efficiency scenarios are based on the following level of performance:

1. Baseline: UDRH. Based on the user-defined reference home (UDRH) from the 2019 RNC baseline study, given that modular homes are subject to local codes.
2. Enhanced: RNC program. Based on program home averages, given that modular homes are already eligible for the RNC program. Uses the DOE's Zero Energy Ready Homes Program values in the absence of available program data.[116]
3. Highest: Passive House/Zero-net Energy (PH/ZNE). An option reflecting high-performance levels such as achieved through PH or ZNE practices.[117, 118, 119] The PH/ZNE model values are based on minimum suggested values under Passive House Institute U.S. (PHIUS) 2021+ standards.[120,121]

[116] U.S. Department Of Energy, "DOE Zero Energy Ready Home National Program Requirements (Rev. 07)," *energy.gov*, last modified May 01, 2019, https://www.energy.gov/sites/default/files/2019/04/f62/DOE%20ZERH%20Specs%20Rev07.pdf.
[117] NMR Group, Inc., "2019 Residential New Construction Baseline/Compliance Study," Submitted to *The Massachusetts Electric and Gas Program Administrators*, April 1, 2020, https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf.
[118] The team leveraged Department of Energy's (DOE) Zero-Energy Ready Home (ZERH) specification values in the absence of a program-specific value. The ZERH specifications result in homes that have an average HERS rating between 50 and 55 and compares to average program efficiency values.
[119] U.S. Department Of Energy, "DOE Zero Energy Ready Home National Program Requirements (Rev. 07)," *energy.gov*, last modified May 01, 2019, https://www.energy.gov/sites/default/files/2019/04/f62/DOE%20ZERH%20Specs%20Rev07.pdf.
[120] ZNE homes require at least some on-site renewable energy generation to technically be zero-energy. This prototype category does not include the renewable energy system required to bring the home to full ZNE, like the Department of Energy's Zero Energy Ready Home concept.
[121]Google Maps, "PHIUS Climate & 2021 Prescriptive Snapshot Map," Map. United States, accessed October 2021, https://www.google.com/maps/d/u/0/viewer?mid=1Gy69_ozJC1mG4sHZuURB5b33G_ERXFWS&ll=42.289737936994754%2C-71.64213724193927&z=11.

Table 27: Efficiency Values for Single-family Modular Prototype Energy Models

Component	Baseline (2019 UDRH)	Enhanced (Program Average,[a] ZERH[b])	Highest (PH/ZNE, no renewables)[c]
Above grade wall R-value (conditioned to ambient)	21.8	21.3[a]	46
Ceiling R-value (flat attic)	43.8	47.3[a]	77
Foundation wall R-value (conditioned basement)	14.3	15[e]	15 cavity + 10 continuous
Unheated slab R-value (below grade)	4.7	4.7[a]	24
Window U-factor	0.29	0.27[b]	0.16
Window SHGC	0.35	0.29[e]	0.29[e]
Air infiltration (ACH50)	3.1	2.3[a]	0.6
Duct LTO	3.8 (ducted), 0 (ductless)	1.8[a] (ducted), 0 (ductless)	0[d]
Duct insulation R-value (attic)	6.6	8.0[b]	8.0[e]
Duct insulation R-value (other locations)	6.0	8.0[b]	8.0[e]
Lighting and Appliances	100% LED and ES appliances (all electric)[e]		
Ventilation	Exhaust only	Exhaust only	ERV, 0.79 SRE
Natural gas furnace with central AC and natural gas water heater prototypes			
Cooling (SEER)	Central AC (14.1)	Central AC (14.1)[a]	Central AC (15)[e]
Heating (AFUE)	Furnace (93.9)	Furnace (95.3)[a]	Furnace (97)[e]
Water heater (EF)	Instantaneous (0.95)	Instantaneous (0.95)[a]	Instantaneous (0.97)[e]
All-electric prototypes			
Cooling (SEER)	MSHP (19.7)	MSHP (20.0)[a]	MSHP (20.0)[e]
Heating (HSPF)	MSHP (10.5) w/resistance back-up	MSHP (10.9)[a] w/resistance back-up	MSHP (12.0)[e] w/resistance back-up
Water heater (EF)	HPWH 3.34	HPWH 3.50[a]	HPWH 4.00[e]

[a] Average program home efficiency from 2019 baseline study.
[b] ZERH specifications.
[c] PHIUS 2021+ prescriptive specifications for Worcester, MA.
[d] Duct system within thermal boundary; no duct leakage.
[e] Assumption by evaluation team.

MULTIFAMILY MODULAR PROTOTYPE MODELS

Table 28 describes the efficiency values for the multifamily modular units (both the end unit and the interior unit prototypes). The most efficient values for each set of measures are identified in blue. The efficiency scenarios are based on the following level of performance:

1. Baseline: UDRH. Based on the preliminary low-rise multifamily UDRH values from the draft MA20R30 Low-Rise Multifamily Baseline Study, given that modular multifamily units are subject to local energy codes.
2. Enhanced: RNC program. Based on low-rise program multifamily averages, given that modular homes are already eligible for the RNC program. Uses the DOE's Zero Energy Ready Homes Program values in the absence of available program data.

3. Highest: Passive House/Zero-net Energy (PH/ZNE). Assumes similar values used in the single-family modular prototypes.

To determine the baseline envelope efficiency values, we applied the ratio between the proposed low-rise multifamily UDRH values[122] and the single-family UDRH values by component type to the baseline envelope efficiencies observed during the 2019 RNC baseline study (Table 27).[123] We did not obtain measure-level efficiency data that could be applied to the enhanced and highest efficiency during the literature review. To overcome the lack of data, we applied the relative improvement percentage of the upgraded building envelope efficiency values used in the single-family prototypes to scale the multifamily baseline efficiency values to "enhanced" and "highest" levels of performance.

[122] The evaluation team leveraged the preliminary low-rise UDRH values that were provided in the Draft Low-Rise Multifamily Baseline Study (MA20R30).
[123] The 2019 RNC baseline reports the nominal insulation-only R-values observed on-site while the UDRH provides U-values for a given assembly, which take into account insulation grade and framing factor. This conversion process converted U-values for a given component type to insulation-only R-values.

Table 28: Efficiency Values for Multifamily Modular Prototype Energy Models

Component	Baseline (2020 MF UDRH)	Enhanced (Program Average,[a] ZERH[b])	Highest (PH/ZNE, no renewables)[c]
Above grade wall R-value (conditioned to ambient)	21.1[e]	20.6[e]	44.6[e]
Framed Floor R-value	23.3[e]	23.3[e]	30[e]
Ceiling R-value (flat attic)	42.5[e]	45.9[e]	74.7 [e]
Window U-factor	0.28	0.28[b]	0.16
Window SHGC	0.29	0.26[b]	0.26[e]
Air infiltration (ACH50)	3.4	2.3[a]	0.6
Duct LTO	5.5 (ducted), 0 (ductless)	3.7[a] (ducted), 0 (ductless)	0[d]
Duct insulation R-value (attic)	6.6	8[b]	8[e]
Duct insulation R-value (other locations)	6.0	8[b]	8[e]
Lighting and Appliances	100% LED and ES appliances (all electric)[e]		
Ventilation	Exhaust only	Exhaust only	ERV, 0.79 SRE
Natural gas furnace with central AC and gas water heater prototypes			
Cooling (SEER)	Central AC (13.8)	Central AC (14.1)[a]	Central AC (15)
Heating (AFUE)	Furnace (93.5)	Furnace (95.3)[a]	Furnace (97)
Water heater (EF)	Instantaneous (0.93)	Instantaneous (0.95)	Instantaneous (0.97)
All-electric prototypes			
Cooling (SEER)	MSHP (15)	MSHP (18)[e]	MSHP (20.0)[e]
Heating (HSPF)	MSHP (8.3) w/resistance back-up	MSHP (10.9)[e] w/resistance back-up	MSHP (12.0) [e] w/resistance back-up
Water heater (EF)	Storage tank 0.93	Storage tank 0.93[e]	HPWH 4.00 [e]

[a] Average low-rise multifamily program unit efficiency.
[b] ZERH specifications.
[c] PHIUS 2021+ prescriptive specifications for Worcester, MA.
[d] Duct system within thermal boundary; no duct leakage.
[e] Assumption by evaluation team.