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Prefabricated Zero Energy Retrofit Technologies: A Market Assessment

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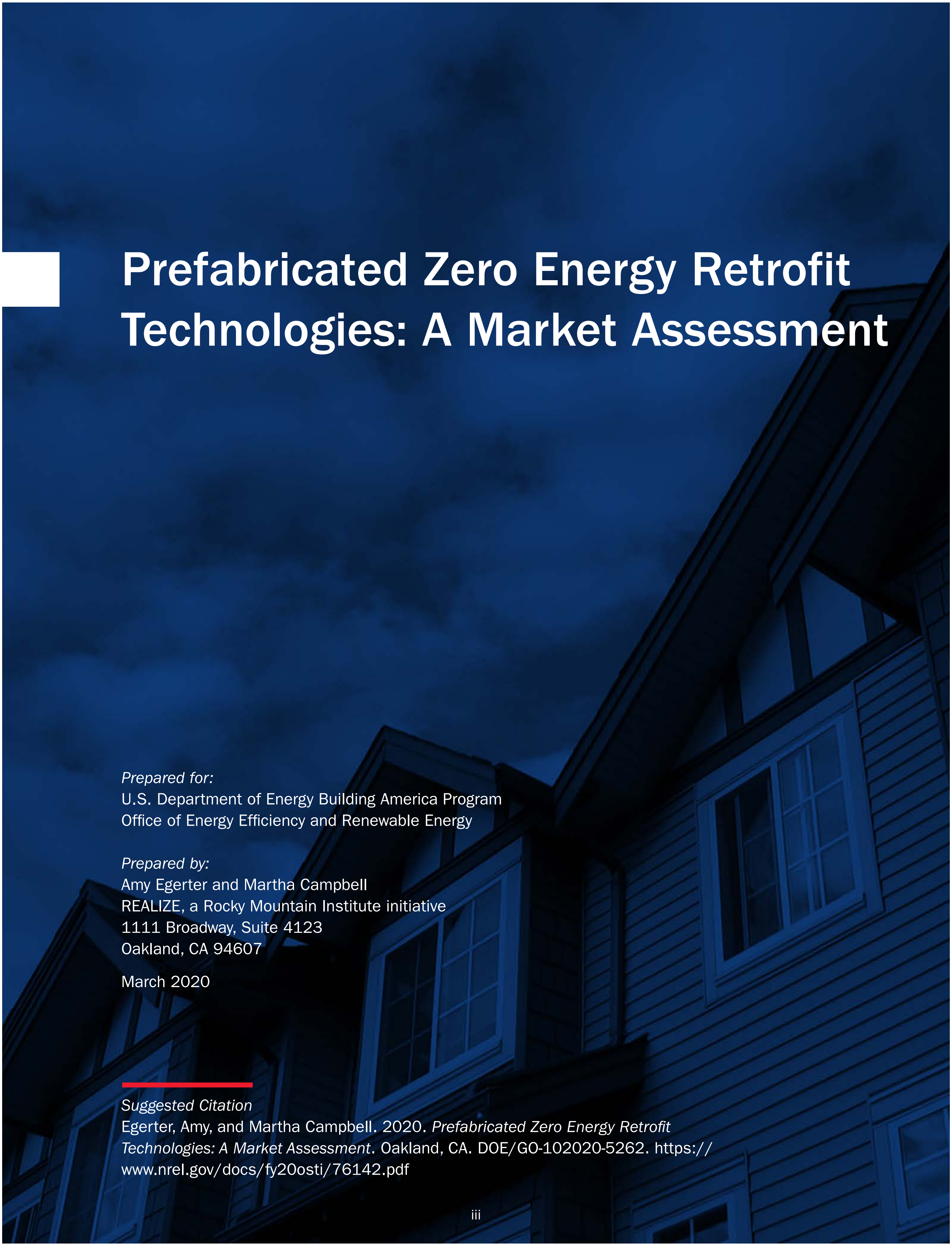

Prefabricated Zero Energy Retrofit Technologies: A Market Assessment

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U.S. Department of Energy Building America Program
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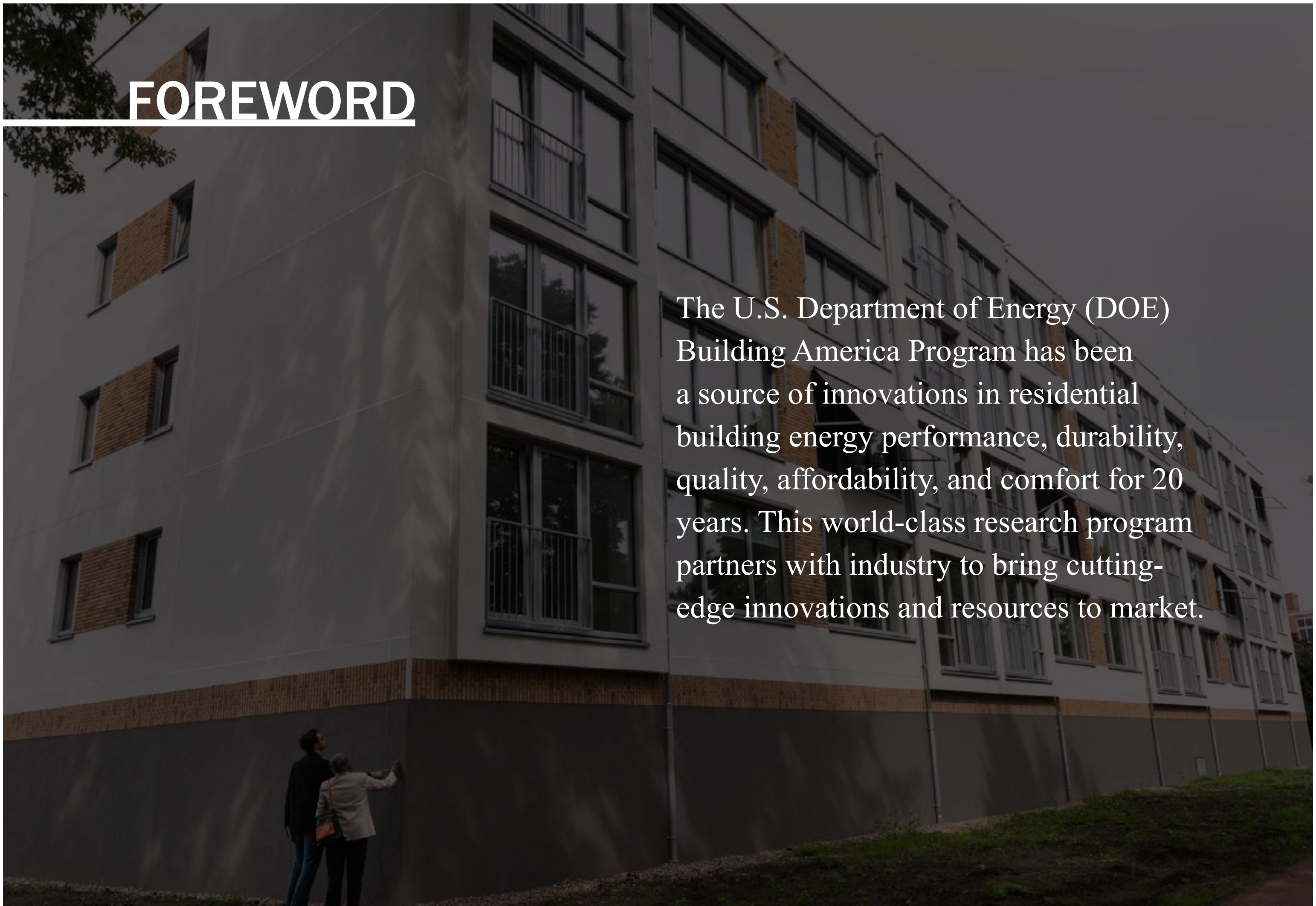
The work presented in this EERE Building America report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

FOREWORD



The U.S. Department of Energy (DOE) Building America Program has been a source of innovations in residential building energy performance, durability, quality, affordability, and comfort for 20 years. This world-class research program partners with industry to bring cutting-edge innovations and resources to market.

The Building America Program supports the DOE Building Technologies Office Residential Building Integration Program goal to:

> By 2025, reduce the energy used for space conditioning and water heating in single-family homes by 40% from 2010 levels.

In cooperation with the Building America Program, Rocky Mountain Institute's REALIZE team is one of many Building America teams working to drive innovations that address the challenges identified in the Program's Research-to-Market Plan.

This report, "Prefabricated Zero Energy Retrofit Technologies: A Market Assessment," explores the current state of technology and market gaps for industrialized retrofits as demonstrated by Energiesprong in the Netherlands and provides key recommendations for how the United States might develop its own capacity for such retrofits.

As the technical monitor of Building America research, the National Renewable Energy Laboratory encourages feedback and dialogue on the research findings in this report as well as others. Send any comments and questions to building.america@ee.doe.gov.

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LIST OF ACRONYMS

BGDD	Bouwgroep Dijkstra Draisma (Dutch retrofit panel manufacturer)
CNC	computer numeric control
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
ERV	energy recovery ventilator
HVAC	heating, ventilating, and air conditioning

EXECUTIVE SUMMARY

This research was conducted by Rocky Mountain Institute's REALIZE team with support from the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Buildings Technologies Office.

The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy's (EERE's) mission is to "create and sustain American leadership in the transition to a global clean energy economy."[1] EERE's vision is a strong and prosperous America powered by clean, affordable, and secure energy. In support of this vision, one of EERE's strategic pillars is to stimulate the growth of a thriving domestic clean energy manufacturing industry. This report seeks to identify products in the European and U.S. markets that can enable a more integrated and standardized approach to conducting zero energy retrofits by leveraging off-site construction and manufacturing. Greater integration of energy conservation measures into prefabricated building components will further enable efficiency adoption, while reducing project complexity, risks, and costs.

In particular, this report discusses the current state of integrated retrofit technologies as demonstrated by Energiesprong in the Netherlands and assesses similar product availability for the U.S. market. Energiesprong is a Dutch public-private partnership that has pioneered the development of a semi-industrialized net zero energy retrofit package and has applied this approach on approximately 5,000 low- and mid-rise multifamily retrofits to date, with roughly another 100,000 units of multifamily[2] demand aggregated across Europe. REALIZE, a Rocky Mountain Institute initiative, aims to catalyze a similar retrofit approach in the United States in partnership with other market facilitators, such as New York State's Research and Development Authority's RetrofitNY program as well as federal and state government agencies such as DOE, California Energy Commission, and Massachusetts Department of Energy Resources.

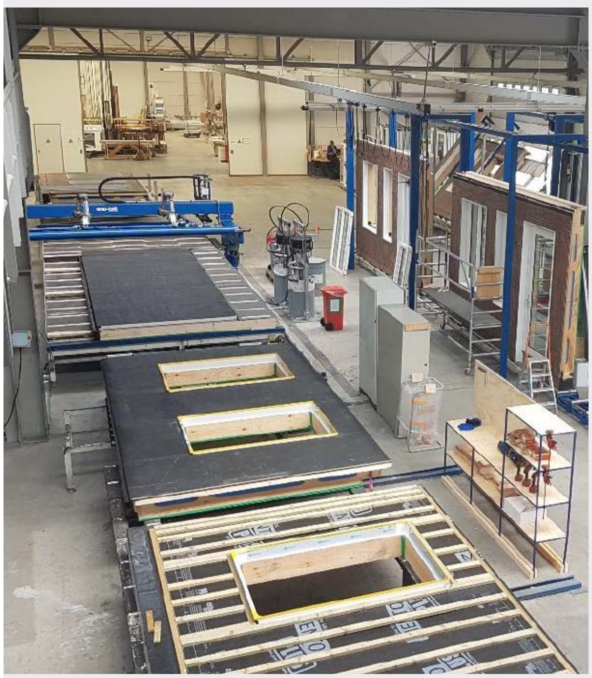
This report catalogues facade panel and mechanical system innovations created for multifamily housing net zero energy retrofits in the Netherlands and the technologies available

[1] https://www.energy.gov/eere/about-office-energy-efficiency-and-renewable-energy.

[2] For purposes of this report, "multifamily" is defined as 5 or more units, "low-rise" as 4 stories or less, "mid-rise" as 5 to 9 stories, and "high-rise" as 10 or more stories.

and still needed in the United States to enable a similar retrofit solution. We see these technologies as having the potential to unlock the retrofit market as a function of turning the retrofit process into a product, as opposed to a complex set of activities that increase an already complex capital improvement process. Although many of the technologies utilized for multifamily housing in the Netherlands can ultimately be applied to single-family retrofits as well, this report focuses on their development and adoption in the multifamily market.

The facade system for this retrofit approach consists of a fully unitized panel that attaches to the exterior of an existing building. The unitized panel has all finishes, doors, and windows included in the panel, such that it is ready for installation once it reaches the project site. In the Netherlands, there are six panel manufacturers that supply the majority of retrofit panels: Bouwgroep Dijkstra Draisma (BGDD), RC Panels, Stam en Landman, Renolution, Plecht-Vos, and De Groot Vroomshoop. Within that group, the three largest are BGDD, RC Panels, and Renolution. These panel manufacturers all use off-site construction techniques to produce their panels, which vary in manufacturing approach. These manufacturers have built up their operations to meet the demand aggregated for them via Energiesprong. In the United States, there are many prefabricated wall system manufacturers with a focus on new construction; however, none have developed a system specific to retrofits. Adapting the Netherlands' retrofit panel solutions for the U.S. market will require development of geography-specific designs and systems for mid- and high-rise construction. Panel manufacturing processes and facilities that can support both retrofit and new construction panel fabrication on the same production lines will give producers access to another market segment, while enabling flexibility during boom and down cycles in the new construction sector.



For mechanical systems, the recent focus has been on smaller, all-electric, combination systems. Like the facade panels, this type of system configuration enables quick on-site installation and minimizes tenant disruption. There are numerous examples of such systems in the European market and far fewer in the U.S. market. Large, global manufacturers have cited uncertain demand for such systems in the United States as well as issues transferring products here from abroad. If international manufacturers do not bring their products to the United States, existing U.S. combination systems should be redesigned to incorporate heating, cooling, domestic hot water, ventilation, dehumidification, controls, and even battery storage needs for various climate zones.

Overall, the supply of deep energy retrofit packages using panelized and integrated mechanical systems is nascent but growing in the United States. This statement is supported by the level of engagement we have experienced with building portfolio owners, local and state governments, and interested manufacturers through REALIZE's webinars, requests for proposals, and other external outreach. The REALIZE initiative issued a request for proposals in 2018 for a DOE pilot of this retrofitting approach, to which several manufacturers submitted proposals showing willingness to offer such integrated systems (six responses for facade panels and two for mechanical systems). The retrofit market opportunity is large and could even eclipse the new construction market, especially as cities look to adopt more stringent building energy performance codes to meet their carbon emissions reduction goals. This report discusses actions that suppliers, government, research organizations, and market facilitators can take to further this market in the United States, including increased focus on high-performance retrofit product development, making R&D funding available for such product development, and organizing demand to ensure suppliers have a reliable pipeline for such work.

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1 Background and Purpose

The buildings sector in the United States is the number-one carbon-emitting sector, accounting for 39% of annual emissions and 74% of electricity use (U.S. Energy Information Administration 2017). Certain studies predict that 70% of North American floor area that exists today will still exist in 2050 (Abergel, Dean, and Dulac 2017). Therefore, the success of reducing building sector emissions will be largely dependent on addressing the energy consumption of buildings that exist today. The multifamily sector in the United States comprises just under 18% of the total building stock, and the current annual retrofit rate of around 1% per year (IEA 2017) will not result in the transformation needed to reduce emissions from this sector quickly and effectively.

One solution to increasing the retrofit rate in the multifamily residential sector is a model created by the Dutch public-private partnership, Energiesprong. The organization acts as a market development team to combine demand aggregation with coordination of the supply chain to deploy prefabricated, mass-scale retrofits. Energiesprong has facilitated more than 5,000 multifamily unit retrofits, with another 100,000 planned across the European Union.[3] Although much of Energiesprong's contribution to deep energy retrofits lies around their organization of the market to supply net zero retrofit packages, this report specifically focuses on the technologies that have been developed in response to Energiesprong's vision for easily installed, minimally disruptive retrofits that can be scaled across large numbers of buildings. Similarly, although policy and incentives played a role in jump-starting the market in the Netherlands, an in-depth exploration of these topics is beyond the scope of this report.

The components of the retrofit solutions developed in the Netherlands can be sorted into two major categories: facade panels that are applied to the exterior of a building and all-electric mechanical systems. We see these technologies as having the potential to unlock the U.S. retrofit market as a function of turning the retrofit process into a product, as opposed to a complex set of activities that compound an already complex capital improvement process. This report compares the Dutch approach to the technologies currently available in the United States in an effort to understand how a similar retrofit model could be implemented across the United States.

Figure 1. Energiesprong project before (left) and after (right) renovation

Photos courtesy of Energiesprong (left) and Rocky Mountain Institute (right)

[3] According to interviews with Energiesprong staff.

Rocky Mountain Institute's REALIZE initiative, which includes numerous partner organizations, aims to organize a retrofit platform similar to Energiesprong in the United States, starting with the affordable multifamily sector. REALIZE is targeting commonly seen multifamily building types in regions with a high density of multifamily housing to expedite scaling of this approach. Although preliminary models will be for the affordable multifamily sector, REALIZE hopes to enable this retrofit methodology in the larger multifamily market, the single-family market, and potentially the small- to medium-sized commercial market segment through the development of new technologies and business models.

The main purpose of this report is to identify technology gaps in the United States that must be addressed in order to enable an Energiesprong-style technological approach to retrofitting buildings. This report discusses the state of Dutch technologies deployed on projects retrofitted under the Energiesprong program and their applicability to the United States market with regard to both facade panels and mechanical systems. Based on this information and the state of the U.S. facade panel and mechanical system markets, we present recommendations to expedite the deployment of Energiesprong-style retrofit products in the United States.

1.1 Energiesprong Background[4]

Energiesprong began its program with €50 million ($55 million[5]) in research and development funding from the Dutch government. €40 million of this funding ($44 million) was used to develop residential interventions, both single family and multifamily. As they set out to build a solution to transform the existing building stock in the Netherlands, the organization began by assessing the existing building stock to target their solution toward the largest number of buildings with the highest energy use, as well as by formulating a financing structure to incentivize building owners to act.

The total size of the residential market in the Netherlands is 7.5 million homes. Of those homes, 2.4 million are social housing (government subsidized), 0.6 million are market-rate rentals, and the rest are owner-occupied. To determine the most important and easily addressable building stock, Energiesprong conducted a national typology study. The social housing row house typology was found to be a large, homogeneous building stock, accounting for 80% of heating energy used in the residential sector, making it the most scalable and impactful typology to target. Thus, social row housing typically built in the 1970s became the ideal typology for developing a preliminary retrofit model (see Figure 2). These row houses were ideal not only because of their similar ownership structure, geometry, and energy use profile, but also because they would be entering the age where a major capital improvement would be needed (approximately 40 years of age).

[4] The background information presented in this section was gathered through interviews with Energiesprong staff.
[5] Assuming an exchange rate of 1.1.

Figure 2. Typical row house typology in the Netherlands before (right side) and after (left side) retrofit

Photo courtesy of Energiesprong

Once this building type was selected, Energiesprong set out to foster the design of preliminary retrofits and catalyze the facade and mechanical system manufacturers in the Netherlands. Energiesprong defined the energy savings targets and other building performance requirements for the retrofit designs and engaged with manufacturers to develop prototype solutions that later translated into product line development. In recent years, the preliminary model for row-house-style renovations has been adapted to mid-rise applications in an effort to expand and eventually capture all of the major building types found in the 2.4-million-unit social housing sector. The typology study, combined with the development of a set of prescriptive packages, supporting financing structures, and committed market actors are all key strategic takeaways from the approach the Dutch took in organizing the market.

Further research with building owners also found that financing was a major barrier that kept the demand side from acting on retrofits. To address this, Energiesprong proposed a new law that would allow tenants to pay the equivalent of an energy bill directly to the property owner, solving the split incentive issue on tenant metered properties. This enabled a financing mechanism where the cost of the retrofit incurred by the building owner could be paid back through energy bill savings observed by the tenants. In Figure 3, net zero energy (NZE) investment represents the capital investment made on the rental unit in order to bring its energy use to net zero. Energiesprong's ultimate goal is to bring incremental package costs (the current premium that is paid for high-performance/energy-efficient building components) down to where they can be financed entirely through operational savings.

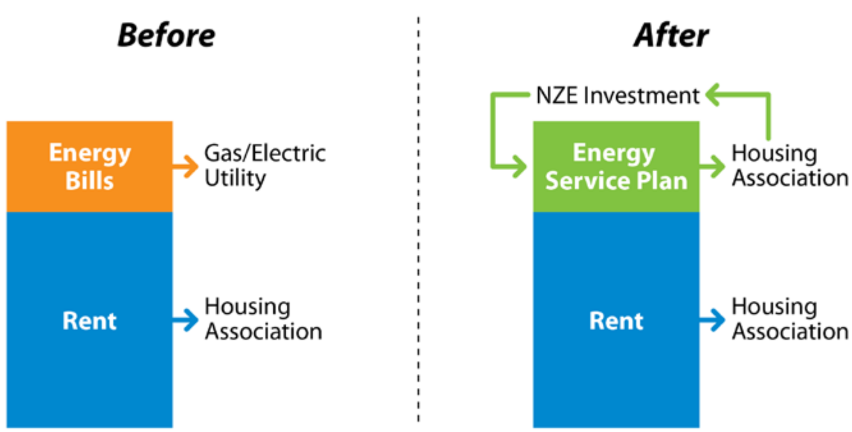

Figure 3. Schematic of the Energiesprong financing model

2 Facade Panels

One of the signature innovations of the Energiesprong style of retrofitting a building is the unitized facade panel that wraps around the exterior of the existing structure and significantly improves thermal performance of the envelope. This approach is especially useful in climate zones where the majority of the energy burden is made up of thermal loads and where significantly reducing thermal loads is required to get a building to net zero. These panels, constructed to Passive House levels, are also desirable for their resilience benefits during extreme weather events, such as heat waves and cold snaps. Unitized panels are also completely self-contained, with all components installed in the panel before it is transported to the site. This means that structural framing, insulation, windows, doors, and air sealing are all included in a unitized panel.

In the following subsections, we present a review of the facade panel manufacturer landscape in the Netherlands and then assess the availability of similar products in the United States.

2.1 Netherlands Market Overview

There are currently about 25 manufacturers producing building panels in the Netherlands for various applications. Six manufacturers provide the majority of Energiesprong retrofit panels: Bouwgroep Dijkstra Draisma (BGDD), RC Panels, Stam & Landman, Renolution, Plechtvos, and De Vrooms Hoop. This section describes the facilities, practices, and panel designs of the three largest suppliers: BGDD, RC Panels, and Renolution. All three suppliers existed prior to Energiesprong's founding; however, they were able to establish factories and a standardized retrofit product after Energiesprong's large demand aggregation agreement that demonstrated hard and soft commitments of more than 100,000 units.

All three of the highlighted manufacturers provide integrated panel solutions, which include windows and finishes when delivered to the site. Another signature element of the Energiesprong approach is beginning the retrofit process by scanning the building to develop a digital model of existing conditions. This is done with 3D imaging, which uses lasers to create a digital point cloud, or photometric scanning, which uses photos and triangulation algorithms. The digital point clouds and triangulated photographs are then translated into a building information model that represents existing conditions. From there, the retrofit panels are designed to accommodate the existing conditions, after which designs are converted to a CAD/CAM for input into manufacturing equipment. A computer numeric control (CNC) machine then cuts components of the retrofit panels to the correct sizes based on the original geometries input from the point cloud. The process varies by company and depends on the structural material and cladding of the panels. A comparison of the approach and background for the three highlighted manufacturers is included in Table 1.

Table 1. Comparison of Facade Manufacturing Facilities for Three Main Providers*

Facade Manufacturer	Structural Material	Engagement With Energiesprong Since	Factory Automation	Annual Production Volume	Product Warranty Term Length
BGDD	Timber framed	2013	Moderate	At least 350 homes per year	25 years
RC Panels	Structurally insulated panel	2016	High	500–600 homes per year	10 years
Renolution	Light gauge steel	2015	Low	~200 homes per year	Not disclosed

* This table is not meant to be exhaustive, but rather representative of the common types of panel systems used in the Netherlands.

2.1.1 Panel Manufacturer Market Development

The panel manufacturers generally attribute their establishment of off-site manufacturing facilities to several factors: the shrinking labor force in the Netherlands, the growing need for housing stock upgrades, and the guidance and demand organized by Energiesprong. Energiesprong was able to reduce risks to manufacturers by (1) creating homogenous product demand with a committed retrofit inventory, (2) bringing transparency to the retrofit market for key actors, and (3) establishing necessary gap funding subsidies.

BGDD, an early adopter, conducted its own market research and determined that if it did not invest in factory automation, the cost to renovate buildings would be orders of magnitude larger. This investment in automation pushed BGDD to convert from a typical general contractor firm to a design-build firm so that they could maintain control over the design, manufacturing, and installation process. RC Panels, on the other hand, was already seeing the demand generated by Energiesprong and the preliminary project examples when they decided to adapt an existing product for retrofit use and more slowly automate their production line.

BGDD also invested in additional research after Energiesprong provided design guidelines for their proposed retrofit model. For BGDD, the preliminary hypothetical design and field test took four months for a single panel. RC Panels had a more expedited timeline of three months to manufacture panels for an entire project, because they agreed to provide panels while still developing the panel design. Both companies determined that the technology would not be difficult to produce, but the cost-effectiveness depended heavily on having a constant flow of project volume to keep the factory running.[6]

Furthermore, all three companies produce both retrofit panels and new construction panels on the same manufacturing lines. By designing both types of panels to be produced on the same equipment, the manufacturers effectively double their market for their factory, creating a better business case for investing in more advanced manufacturing technology in their factory.

2.1.2 Example Panel Manufacturers

2.1.2.1 BGDD

BGDD is a design-build firm originally founded in 1904 whose recently developed renovations group provides exterior, panelized solutions using enhanced robotic fabrication.[7] BGDD was one of the first facade panel suppliers for Energiesprong retrofits and has since established a factory (see Figure 4) in Dokkum in the northern Netherlands that can quickly produce unitized panels for retrofits and new constructions. For new construction projects, the company has also developed a kitchen and bathroom pod for quick installation. According to BGDD's Biense Dijkstra, their new factory is targeted to produce eight panels per day, with a maximum of one panel every 45 minutes when the machines are running at 100% capacity (Doodeman 2018). The factory was established in partnership with H&M Wood[8] to design the timber frame production line using the "Robi-One" robot. Economic incentives in the northern Netherlands also contributed to funding the development of this factory.

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[6] Information from interviews with BGDD staff and RC Panels staff.
[7] For more information, see BGDD's website: https://bgdd.nl/.
[8] For more information, see H&M Wood's website: https://www.h-m.nl/en.

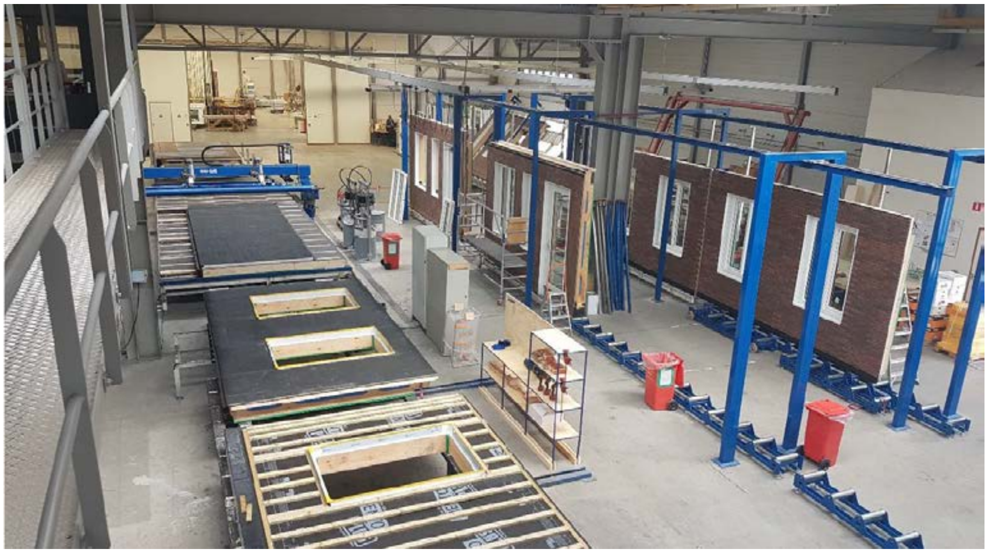

Figure 4. BGDD's Dokkum factory floor[9]

Photo courtesy of BGDD

The factory[10] uses drone-generated photometrics to develop a building information model, which then provides dimensions to their CNC machine for the cutting and assembly of the timber framing and rigid insulation, as seen in Figure 5.

Figure 5. Timber frame manufactured with robotic exterior cladding application (left) and CNC machine (right)

Photos courtesy of BGDD

Factory workers install triple-pane windows and insulation between timber frame members by hand and a robot applies the facade finishes and nails the components together. The materials used in the panel have been selected with end-of-life considerations in mind. BGDD uses wood, cellulose, recycled paper, mineral wool, and brick cladding in their panels because they are more sustainably sourced and can be recycled at end of life.

[9] For more information on this BGDD production line, see: https://www.h-m.nl/nl/over-ons/nieuws/h-m-mr-17-metselrobot-en-hsb-productielijn-geleverd-bij-bouwgroep-dijkstra-draisma.htm.
[10] For a video about this process, see: https://www.youtube.com/watch?v=JUnzHgVTW6U.

The panels are designed to be installed close to the existing facade via a hook system, with insulation then blown into any small gaps remaining between the existing and new facade.[11]

BGDD does not currently supply their panels to other installers because of the amount of design rework needed for different details. The company had attempted to do so in a previous project but noticed drastic decreases in the amount of automation able to be applied during the fabrication process.[12]

2.1.2.2 RC Panels

RC Panels[13] produces a structurally insulated panel with a patented glue method. The company previously manufactured panels for refrigerated transport trailers and modular housing but began to manufacture retrofit panels in 2016 after Energiesprong's large demand aggregation agreement. They had heard about the issues in the net zero retrofit market and thought that their product could be easily adapted to that context.

RC Panels has already achieved 30% cost reductions in production, with an aspiration to achieve an additional 10% with their next iteration of panel manufacturing. Most of these cost reductions stem from the projected scale of production (1,000 units per year) that justified around a €5 million ($5.48 million[14]) investment in automation to lower labor costs. RC Panels works with architects to design, fabricate, and deliver the panels to the contractor for installation. Their panels consist of a sheet of rigid fiberglass, oriented strand board, graphite-infused expanded polystyrene, and another sheet of rigid fiberglass. This sandwich is then glued together using a vacuum sealing method and then cut to the dimensions of the building using a CNC machine. RC Panels also uses 3D imaging to create a building information model and then translates this to the CNC machine. The company uses robotics to apply a brick veneer to panels, although they can also manufacture a wood or cane cladding for their panels. Windows and doors are installed in the factory by attaching to wood blocking that is strategically placed in the foam panel earlier in the process. The panel seams are sealed using a gasket or sealant product, typically bringing the whole-building airtightness levels to below 0.4 ACH.[15]

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[11] According to interviews with BGDD staff.
[12] According to interviews with BGDD staff.
[13] For more information, see the RC Panels website: http://rcpanels.nl/.
[14] Exchange rate of 1.1 assumed.
[15] According to interviews with RC Panels staff.

Figure 6. RC Panels production facility in Lemelerveld, Netherlands

Photo taken during REALIZE factory site visit

Figure 7. Examples of facade claddings at RC Panels factory

Photo taken during REALIZE factory site visit

RC Panels' highest-performance panel has an R-value of 39.8 and is 5.5 inches (14 cm) thick.[16] RC Panels also uses triple-pane glazing in their panels. The company claims that their panels are the thinnest on the market, and they can hang their panels from two ledges attached to the facade. These panel systems do not require any structural reinforcement of the building because of their light weight (7.2–8.2 lb/ft^2; 35–40 kg/m^2). Typically, the panel will descend around 1 ft (30 cm) into the ground to insulate the below-grade portions of the building.

[16] According to the RC Panels SIP brochure: http://www.rcpanels.nl/app/uploads/2017/06/170110_RC_panels_SIP_brochure-email.pdf.

RC Panels is currently looking to collaborate with Kingspan to deliver a roof panel with integrated solar as well.[17]

Figure 8. Installation process images for RC Panels

Photos taken during REALIZE site visit

2.1.2.3 Renolution

Renolution[18] produces light gauge steel panels that have integrated ducting for heating and/or ventilation and are designed to be earthquake resistant.[19] Renolution was founded as a prefab whole-home builder, but they set up production facilities geared toward net zero energy retrofits because of the demand generated from Energiesprong's market development work. Renolution completed its first retrofit projects in 2015 and partners with contractors familiar with their products to install their panels. Typically, the panels weigh 6.1–10.2 lb/ft^2 (30–50 kg/m^2) and do not require the building to undergo structural improvements such as reinforcing the foundation.

Figure 9. Renolution panel production[20]

Photos courtesy of Renolution

[17] According to interviews with RC Panels staff.

[18] For more information, see the Renolution website: https://renolution.nl/.

[19] For more information on earthquake resistance, see: https://renolution.nl/aardbevingsveilig/.

[20] For additional panel production information, see: https://renolution.nl/renovatie/.

Renolution also uses 3D scanning to develop a building information model that aids in the fabrication process. The panels use triple-glazed windows, insulation, and can include integrated ducting for a heat/energy recovery ventilator or air-source heat pump.

Figure 10. Ducting integrated into Renolution facade panel

Photo courtesy of Renolution

Figure 11. Project example of Renolution panels

Photo taken during REALIZE site visit

2.1.3 Dutch Technology Transfer Barriers

Dutch suppliers have responded quickly and have scaled up production of unitized retrofit panels to meet the demand aggregated by Energiesprong. Energiesprong liaised between building owners and suppliers, utilizing a request-for-proposal-like instrument that provided specific committed unit volumes from owners and then combined this with performance requirements and performance verification protocols. This created clarity around desired products, building owner willingness to pay, and therefore tenable R&D and production capacity investments for suppliers. This approach has been very successful in the Netherlands and is highly recommended for the U.S. market if the development of similar products for simplifying net zero retrofit projects is desired.

The technologies developed in the Netherlands could be transferred as they currently are to similar building typologies in the United States; however, there are several gaps in the Dutch technologies that would need to be addressed if this type of retrofit were to be applied to a broader spectrum of buildings in the United States. These areas include:

1. **Mid-rise (5–9 stories) and high-rise (10+ stories) solutions:** In the United States, many multifamily housing developments are more than five stories tall. None of the panel systems in the Netherlands have been installed on buildings taller than five stories. At present, panel systems are attached to the nonstructural facade elements or the underlying structural masonry, depending on the panel type weight. In a mid- or high-rise context, the need for panel stacking or for panels to provide structural reinforcement is likely, unless panels can be made at very light weights. The potential for structural integrity of stacked panel systems for higher-rise applications should be investigated, in addition to the threshold at which an additional structural footing or other structural reinforcements would be needed.

2. **Seismic design:** Implementation in high seismic zones in the United States would require additional panel design considerations. Renolution has developed a panel system that incorporates minimal seismic design criteria; it is unclear whether this panel and its attachments would comply with earthquake design criteria in areas like California. Furthermore, these panels have not been tested for seismic criteria on high-rise buildings, which would have different structural design considerations.

3. **Mechanical integration:** Panel manufacturers would need to collaborate with mechanical equipment manufacturers to design a suite of installation options based on the varied building geometries in the United States. Dutch manufacturers have been integrating their system designs, particularly with ductwork, but there could be additional design development in the United States to integrate mechanical units into the facade to avoid taking up space on the interior or rooftop of a building.

4. **Climate-specific design criteria:** The Netherlands has a similar climate throughout the country, so there has not been much variation in climate-specific design of exterior panels. Because of the variance in climates in the United States, solutions would need to be developed to accommodate different climate zones (e.g., R-value variations, mechanical system sizing variations, and so on).

2.2 United States Market Overview

Based on both desk and primary research, including interviews, there are currently no U.S. manufacturers producing unitized panels as a high-performance retrofit solution. There are several aspects of current manufacturer practices and panel design that limit the potential for scalable production of high-performance retrofit panels:

- **Level of prefabrication and/or unitization is lacking**: Based on interviews with manufacturers and site visits, it appears most manufacturers do not use advanced fabrication technologies. Few companies have leveraged robotics or automation in their production facilities, which means that costs to adjust product design are high. This is especially valuable to enabling the use of one manufacturing line for both new-build and retrofit panel production. Unitization is seen as essential for speedy on-site installation and to reduce risk of moisture intrusion at the fenestration connections; however, few U.S. manufacturers install windows and doors in the panels before delivery to the site.

- **Some current panel systems might not be well-suited for taller existing structures**: Most panels made in the United States use an open timber frame or steel frame, which will likely not translate well to taller existing structures because of structural and fireproofing concerns. Developing lightweight, fireproof panels could change the business models of such manufacturers, because it could require a switch in structural materials.

- **Panels are geared toward new construction**: There is little range currently in the market between modular buildings (a building or rooms that are fully constructed off-site and then installed via stacking or other fast connections) and individual facade components (prefabricated walls without windows or doors installed). Retrofit panels as developed in the Netherlands fall between these two and are fully fitted out on the exterior, while remaining unfinished on the interior in order to attach to the building.

There are several U.S. companies whose products come close to a fully unitized design that could be used as a scalable, high-performance exterior retrofit panel. The panel systems developed by these companies are designed for new construction but could potentially be applied to retrofit projects with some product adjustments. These systems incorporate some important characteristics of unitized retrofit panels, but they lack complete integration—including high-performance control barriers—and none have yet developed a consistent connection system for retrofits. A summary of a few promising products is presented in Table 2.

Table 2. Summary of Prefabricated Panel Systems in the United States*

Manufacturer	Panel System Type**	Main Market Segment	Components Included
Bensonwood	Non-unitized wooden panel	Single-family new construction	Wall, including windows; cladding installed on-site
Blueprint Robotics	Non-unitized wooden panel	Single-family new construction	Wall, including windows; cladding installed on-site
Build SMART	Non-unitized wooden panel	Single-family new construction	Structural framing; windows, insulation, and cladding installed on-site
Centria	Metal structural insulated panel	Commercial new construction and renovations	Complete wall, with windows and cladding installed in factory
Clark Pacific	Precast insulated concrete	Multifamily and commercial new construction	Exterior panel, with windows and insulation installed in factory; interior unfinished
GO Logic	Non-unitized wooden panel	Single-family new construction	Structural framing; windows, insulation, and cladding installed on-site
Island Exterior Fabricators	Unitized metal panel	Mid- to high-rise*** new construction	Rainscreen wall, with windows and cladding installed in factory
Katerra	Unitized wooden panel	Multifamily and commercial new construction	Complete wall assembly with windows, electrical wiring, and fireproofing
Kingspan	Metal structural insulated panel	Commercial new construction	Insulated panels with cladding; windows installed on-site
Kreysler & Associates	Fiber reinforced polymer	Commercial new construction	Architectural cladding systems

*This table is not meant to be exhaustive, but rather representative of the general types of panel systems currently available.

** Unitized panels include all windows, doors, and finishes installed in the factory. Non-unitized panels do not include one or more of these components when delivered to the project construction site.

*** Mid-rise: 5–9 stories; high-rise: 10+ stories.

2.2.1 Key Market Development Recommendations

The current U.S. demand and supply for exterior retrofit panels are both small; however, there are several key actions that can increase the likelihood of manufacturers developing retrofit panels:

1. **Characterize the building stock:** Manufacturers will need to know the building types for which they should develop products. The prevalence of each building type, along with each type's characteristics, will need to be better articulated so that manufacturers can assess the market size and needs for products they develop. A more accurate understanding of building characteristics such as building construction, roof construction, and structural integrity will specifically inform the development of retrofit wall panel systems.

2. **Aggregate demand:** The panel manufacturing market is fragmented and typically consists of small, local fabricators. Some are under the umbrella of a general contractor, while others are slightly larger and ship regionally. Given the high overhead and unpredictable rate of orders for panel fabrication, it is challenging for these companies to change their products or processes to meet the needs of a fully integrated, affordable retrofit solution. A demonstrated and consistent pipeline of high-performance retrofit demand must exist in order for companies to have the confidence to devote R&D resources to retrofit technologies. Organizing demand and presenting it in an actionable way to manufacturers is a role that market facilitators, government, and large portfolio owners can play. This type of "demand aggregation" requires a focused set of activities to demonstrate potential volume in order to attract industry innovators and drive down costs for market adoption.

3. **Provide R&D resources for product innovators:** Funding may be required to supplement manufacturers' R&D budgets, even for large innovative manufacturers. This funding could come in the form of utility R&D dollars and incentives, national laboratory research funding, government agency grants, incentives for facility expansions or developments, or other creative financing models. It may also be helpful to provide resources for potential technologies and innovations that could be applied to a business, highlighting the benefits, costs, and risks of different approaches. These resources will likely only be necessary until manufacturers understand how to change existing practices to meet the needs of the retrofit market. Resources should also target new and disruptive players entering the market, because their resource needs will be slightly different from incumbents' R&D needs.

4. **Develop assemblies for mid- and high-rise building applications:** In multifamily applications in many major cities, fire code does not permit wood-framed facade systems. Lightweight systems with additional structural considerations and stricter fire code adherence will likely be needed for many different typologies in this class.

3 Mechanical Systems

The second key technological aspect of the Energiesprong retrofit is the mechanical system replacement. Energiesprong has chosen an all-electric path to bringing buildings to zero. A number of trends are further reinforcing this approach—specifically, an overarching directive to phase out natural gas use in the Netherlands by 2050. Although there is no similar directive in the United States at a national level, many states and municipalities are considering such strategies in order to meet their climate goals. REALIZE recognizes that as the electric grid becomes cleaner with the installation of additional renewable energy sources, having all-electric systems in place will enable building decarbonization. Furthermore, all-electric systems provide other benefits, such as removing need for gas combustion venting and greater stovetop control through the use of technologies such as induction cook stoves. The following subsections present the current state of the mechanical systems market in the Netherlands and Europe and compare this to the U.S. market to develop recommendations for market development.

3.1 Netherlands Market Overview

Since 2013, Energiesprong has worked in the European market to develop heating, ventilating, air-conditioning (HVAC) and monitoring solutions that meet project goals and can be deployed at scale in a comprehensive instead of fragmented manner. The mechanical systems used in Energiesprong projects typically consist of a heat pump (various types employed) for domestic hot water and space conditioning, a heat recovery ventilation (HRV) or energy recovery ventilator (ERV), a hot water tank, solar panels, a photovoltaic inverter, and printed circuit board controls.

Most Energiesprong retrofits use mechanical components and systems sourced from various manufacturers and are installed on-site. However, some Energiesprong retrofits have used combination systems—which include heating, cooling, domestic hot water, heat or energy recovery ventilation, and controls—all in prefabricated modules. These systems may offer advantages as a more integrated and scalable solution for retrofits as well as new construction. Reduced installation complexity, integrated control and operation of systems, and waste heat capture synergies are some of the potential benefits of combination systems. There are a few mechanical manufacturers in the Netherlands and greater Europe that have begun to develop combination systems that provide multiple services in one unit (typically one- to two-bedroom apartments). As detailed in the following subsections, three key examples of such systems that are used in Energiesprong retrofits are the Factory Zero Integrated Climate Energy Module, the Nilan Compact P line, and the Drexel und Weiss x2 A9.

3.1.1 Example Mechanical Products

3.1.1.1 Factory Zero—Integrated Climate and Energy Model

The Factory Zero Integrated Climate and Energy Model (iCEM)[21] provides hot water as well as space heating and cooling using an air-to-water heat pump that has several configurations to address various existing conditions in which the system might be installed. The system also includes an HRV and a photovoltaic inverter. This solution was developed in collaboration with Mitsubishi, Brink, Ubbink, BASF, and ABB. The system is 2.5 ft x 4.7 ft x 7.7 ft (0.770 m x 1.435 m x 2.350 m).

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[21] For more information on this Factory Zero model, see: https://factoryzero.nl/icem_buitenoplossing/.

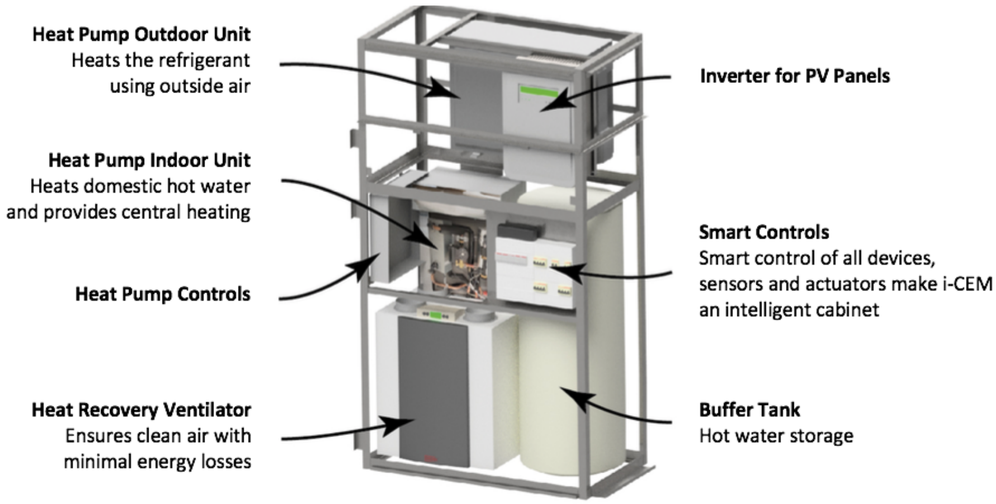

Figure 12. Factory Zero iCEM schematic

Figure from Factory Zero

3.1.1.2 Nilan—Compact P Line

Nilan[22] is also a supplier for Energiesprong projects, offering a wide range of "magic box" solutions that provide heating and cooling, hot water, and ventilation using an HRV. Nilan's systems have electric boiler, air source heat pump, and ground source heat pump options for the Compact P line, which provide hot water and space heating through radiant floors or radiators. Nilan has previously offered a version of this product in North America but decided to withdraw from the United States in 2015. The system is 2 ft x 3 ft x 6.8 ft (0.610 m x 0.900 m x 2.065 m).

Figure 13. Nilan Compact P Air 9 schematic

Figure from Nilan

[22] For more information, see Nilan's website: http://www.nilan.dk/en-gb/frontpage/solutions/domestic-solutions/compact-solutions.

3.1.1.3 Drexel und Weiss—x^2 A9

German manufacturer Drexel und Weiss offers a similar product to Nilan. The x^2 A9 compact module[23] uses an air-source, water-source, or ground-source heat pump to provide domestic hot water and space heating or cooling using hot or cold water in radiant floors or panels. All configurations also provide ventilation using an HRV. The system is 2.8 ft x 2.1 ft x 6.8 ft (0.850 m x 0.650 m x 2.073 m).

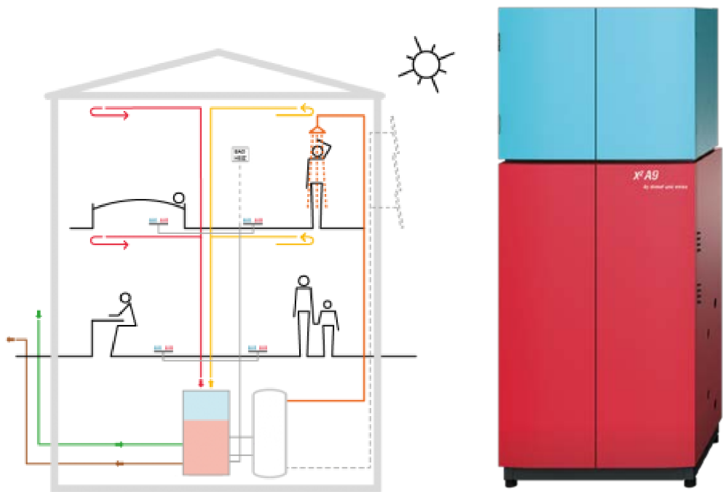

Figure 14. Drexel und Weiss x^2 A9 schematic

Figure from Drexel und Weiss

Many of the major heat pump manufacturers that operate in both the United States and Europe also offer combination systems in Europe. Table 3 summarizes the range of products and functions available in Europe.

[23] For more information on the x^2 A9 unit, see: https://www.drexel-weiss.at/produkte-und-loesungen/einfamilienhaus/x%C2%B2a9/.

Table 3. Combination Systems Available in Europe*

<table>
<tr><th>Manufacturer</th><th>Model or Product Line</th><th>Domestic Hot Water</th><th>Space Heating</th><th>Space Cooling**</th><th>Vent-ilation</th><th>Dehumid-ification</th><th>Other Features/Notes</th></tr>
<tr><td>Factory Zero[24]</td><td>Factory Zero Line</td><td colspan="2">Air-to-water heat pump</td><td>-</td><td>ERV</td><td>-</td><td>Energy module***</td></tr>
<tr><td>Nilan[25]</td><td>Compact P Line</td><td colspan="2">Air-to-water heat pump or ground source water-to-water heat pump</td><td>Reversible cooling circuit, which can cool supply air to ~10°C but does not function as an air conditioning system</td><td>HRV</td><td>-</td><td>Energy module</td></tr>
<tr><td>Viessman[26]</td><td>Vitocal 222-A</td><td colspan="2">Air-to-water heat pump</td><td>Reversible cooling circuit</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Drexel und Weiss[27]</td><td>X^2 line and aerosmart</td><td colspan="2">Air-to-water heat pump, water-to-water heat pump, or ground source water-to-water heat pump</td><td>-</td><td>HRV</td><td>-</td><td>Energy module</td></tr>
<tr><td>Daikin[28]</td><td>Altherma 3</td><td colspan="3">Air-to-water heat pump</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Mitsubishi[29]</td><td>Hydrolution</td><td colspan="3">Air-to-water heat pump</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Zehnder[30]</td><td>ComfoFond-L Q ST</td><td colspan="2">Ground source water-to-water heat pump</td><td>-</td><td>ERV</td><td>-</td><td>-</td></tr>
<tr><td>Panasonic[31]</td><td>Aquarea line</td><td colspan="3">Air-to-water heat pump</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Sanden[32]</td><td>SANCO2™</td><td colspan="2">Air-to-water heat pump</td><td>-</td><td>-</td><td>-</td><td>Requires custom modifications to provide hot water for space heating</td></tr>
</table>

[24] For more information on Factory Zero's products, see: https://factoryzero.nl/products/.
[25] Nilan's Compact P line: https://www.nilan.dk/Default.aspx?ID=392.
[26] Veissman's Vitocal 222-A: https://www.viessmann.co.uk/products/heat-pumps/air-source-heat-pumps/vitocal-222-a-mb.
[27] Drexel und Weiss's x^2 line: https://www.drexel-weiss.at/.
[28] Daikin's Altherma 3: https://www.daikin.be/content/dam/document-library/catalogues/heat/air-to-water-heat-pump-low-temperature/Daikin_Altherma_3/Daikin%20Altherma%203_Product%20Catalogue_ECPEN17-786_English.pdf.
[29] Mitsubishi's Hydrolution: https://mhiae.com/hydrolution/.
[30] Zehnder's ComfoFond-L Q ST: https://www.zehnder-systems.de/erdw%C3%A4rmetauscher-zehnder-comfofond/erdw%C3%A4rmetauscher-comfofond/zehnder-comfofond-l-q-st.
[31] Panasonic's Aquarea line: https://www.aircon.panasonic.eu/GB_en/ranges/aquarea/.
[32] Sanden's SANCO2: http://www.smallplanetsupply.com/sanden/.

<table>
<tr><th>Manufacturer</th><th>Model or Product Line</th><th>Domestic Hot Water</th><th>Space Heating</th><th>Space Cooling**</th><th>Vent-ilation</th><th>Dehumid-ification</th><th>Other Features/Notes</th></tr>
<tr><td>NIBE[33]</td><td>NIBE F line</td><td colspan="2">Air-to-water heat pump</td><td>-</td><td>HRV</td><td>-</td><td>-</td></tr>
<tr><td>Hydrotop[34]</td><td>Hydrotop</td><td>-</td><td>Air-to-water heat pump</td><td>-</td><td>-</td><td>-</td><td>Integrated into building geometry with roof, wall, and chimney options</td></tr>
<tr><td>R&R[35]</td><td>E-Combi Box—Mark 1</td><td colspan="2">Air-to-water heat pump</td><td>-</td><td>ERV</td><td>-</td><td>NIBE and Vaillant products with R&R as system integrator</td></tr>
<tr><td>SystemAir[36]</td><td>Genius Complete</td><td colspan="3">Air-to-water heat pump</td><td>ERV</td><td>-</td><td>Designed to work in cooling mode as well as heating</td></tr>
<tr><td>Clivet[37]</td><td>ELFOPack1</td><td>Desuper heater</td><td colspan="2">Air-to-air heat pump</td><td>ERV</td><td>Yes</td><td>-</td></tr>
<tr><td>Stiebel-Eltron[38]</td><td>Zentral LWZ 604 air</td><td>Desuper heater</td><td colspan="2">Air-to-air heat pump</td><td>ERV</td><td>-</td><td>-</td></tr>
</table>

*This table is not meant to be exhaustive, but rather representative of the general types of combination systems currently available.

** Although heat pump systems can theoretically provide cooling, they are not designed to do so unless otherwise noted in this table because of the mild climate in the Netherlands.

*** Energy modules have all system components housed within one central closet or enclosure.

3.1.2 Dutch Technology Transfer Barriers

Despite the advancements that have been made in European mechanical systems, the market is still building out its capacity for combination systems that are small and can be easily installed in most homes. The following areas are key technology gaps that must be addressed in order to bring similar systems to the U.S. market:

1. **Dehumidification:** Mechanical systems in Energiesprong projects in the Netherlands do not incorporate dehumidification because of the less humid climate. This capability will need to be an option for many locations in the United States.

2. **Cooling:** Although the systems developed in the Netherlands can provide cooling because they typically use heat pumps, the systems are often never used in cooling mode and were not designed with cooling capabilities in mind. The air-to-water heat pump configuration using radiant panels might not be the best

[33] NIBE's F line: https://www.nibe.eu/en-eu/products/heat-pumps/exhaust-air-heat-pumps.
[34] Hydrotop: https://www.hydrotopworks.nl/.
[35] R&R E-Combi Box: https://www.energieverdieners.nl/portfolio/e-combi-box/.
[36] SystemAir's Genius Complete: https://shop.systemair.com/en/genius--complete--unit/p403832.
[37] Clivet's ELFOPack1: http://clivetlive.com/en/web/guest/elfopack1.
[38] Stibel-Eltron's Zentral LWZ: https://www.stiebel-eltron.de/de/home/produkte-loesungen/erneuerbare_energien/lueftung/zentral/lwz_604_air/lwz_604_air.html.

configuration to provide cooling in a hot or humid climate in the United States, because the radiant panels—unlike forced air systems—do not provide latent cooling.

3. **Mid- and high-rise building solutions**: To date, the systems implemented in the Netherlands have not been designed for large multifamily buildings that are above five stories tall. It is possible, given the physical dimensions of the integrated systems, that a centralized system option will need to be developed in the United States for taller buildings. Having the option to implement a standardized system per unit or a standardized centralized system will be key to increased market uptake.

4. **Electrical systems may not be compatible:** European products, like the Nilan Compact series, have different supply voltages than what is typical in the United States. Nilan's Compact P, for example, has an input voltage of 230 V and 50/60 Hz and would need to be modified to the standard U.S. 120 V, 60 Hz before it could be applied to U.S. retrofits. Additional research would be needed to evaluate specific challenges related to the electrical compatibility and to determine modifications required.

5. **UL listing and other certifications:** Manufacturers are reluctant to transfer products because of costs associated with testing and UL certification requirements. These one-time costs and the required time investment have been cited as a barrier, but if there was clearer market demand, manufacturers may justify the time and cost. Further research needs to be conducted to better understand the specifics and severity of this expressed barrier.

6. **Lack of trained maintenance staff:** Manufacturers have expressed concerns around product transfer to the United States if there are no maintenance staff trained to maintain their products.

3.2 United States Market Overview

As with the panel systems, there are currently no mechanical manufacturers supplying to the United States the type of combination, all-electric systems that are being used in the Netherlands. Several companies in the United States have developed more efficient and compact heat pumps but have yet to package additional functions together to create an integrated mechanical solution. Currently, no single product in the United States incorporates heating, cooling, hot water, dehumidification, and heat/energy recovery ventilation into a single system. There are, however, some integrated systems that include more of the desired functionalities. The three most common combinations of functions are:

- ERV with additional heating and/or cooling
- Air-to-air heat pump system providing heating, cooling, and ventilation
- Air-to-water heat pump system providing hydronic heating, cooling, and domestic hot water.

The following table summarizes the features offered by larger manufacturers in the United States:

Table 4. Combination Systems Available in United States*

Manufacturer	Model or Line	Domestic Hot Water	Space Heating	Space Cooling	Ventilation	Dehumid -ification	Other Features/Notes
Build Equinox[39]	CERV	-	Air-to-air heat pump		ERV	Via heat pump	-
Daikin[40]	Residential High Temp Heat Pump	Air-to-water heat pump			-	-	-
Minotair[41]	PENTACARE-V12	-	Air-to-air heat pump		HRV	Via heat pump	Self-contained
Minotair & Sanden[42]	PENTACARE V12 + SANCO2 Gen 3	CO_2 air source heat pump water heater	Air-to-air heat pump		HRV	Via heat pump	Manufacturers partnered to provide all desired outputs
Dandelion Energy[43]	Dandelion Air	Geothermal water-to-air heat pump			Supply only without heat recovery	-	Self-contained, with fans for ventilation distribution
Aermec[44]	ANK (2–4 tons)	Air-to-water heat pump			-	-	Self-contained
Chiltrix[45]	CX34	Air-to-water heat pump			Supply only without heat recovery	Dynamic humidity control via coils	Interior ductless diffuser
Therma-Stor[46]	Integrated energy recovery ventilator	-	Air-to-air heat pump		ERV	-	System under development through Building America project and not yet commercially available; self-contained air-to-air heat pump with energy recovery

*This table is not meant to be exhaustive, but rather representative of the general types of combination systems currently available.

[39] Build Equinox's CERV: https://www.buildequinox.com/thesystem/.
[40] Daikin's heat pump: https://www.daikin.com/products/ac/lineup/heat_pump/index.html.
[41] Minotair's PENTACARE V12: https://www.minotair.com/home_en/.
[42] Sanden's SANCO2: https://www.sandenwaterheater.com/products/.
[43] Dandelion Energy: https://dandelionenergy.com/.
[44] Aermec's ANK: https://www.aermec.us/products-2/air-to-water-units/ank/.
[45] Chiltrix's CX34: https://www.chiltrix.com/.
[46] Therma-Stor: http://www.swinter.com/wp-content/uploads/VICS-v7.pdf.

3.2.1 Key Market Development Recommendations

Through manufacturer engagement, there have been two consistently cited barriers to producing combination systems similar to those developed in the Netherlands: lack of a large market for the product and lack of internal development funding. To overcome these barriers, there should be additional focus placed on demand aggregation and R&D resources, similar to those recommended in the U.S. panel manufacturers section of this report. Another way to stimulate the development of these combination systems would be to also market the systems toward low-load new construction, which provides a large market that needs the same systems as retrofits.

Additionally, there are several technology barriers that should be addressed before the desired mechanical systems can be widely deployed in the United States:

1. **Combine existing products to achieve all functionalities needed:** Many of the products available in the United States offer nearly all the functionality needed to meet REALIZE specifications, but there is a notable market shortcoming in that none of the products include both energy recovery ventilation and domestic water heating. Minotair and Sanden have partnered to integrate their pre-existing HVAC and domestic hot water systems in an integrated package to meet the growing market demand (see Table 4). Larger companies, such as Panasonic, Daikin, and Mitsubishi, offer all the required products but do not have them integrated into the same system. Across the U.S. market, there is a clear opportunity to combine and package equipment into one unit.

2. **Develop smaller system sizes for multifamily units:** The majority of heat pump heating and cooling systems do not come in a size smaller than 24,000 Btu/hr (2 tons), which is far more than the anticipated system size needed for one multifamily dwelling. In REALIZE's zero energy ready analysis (Egerter et al. 2018), air-to-air heat pump systems could be sized as small as 11,000 Btu/hr and still meet ventilation loads if Passive House construction techniques were used for such retrofits. Regardless, manufacturers should update their product size offerings to respond to more and more cities adopting more stringent energy codes, which will require much more robust thermal envelopes and lower air infiltration rates, resulting in significantly lower load.

3. **Design systems so that extensive electrical upgrades are not needed**: The proposed retrofit model entails full building electrification of end uses, which can require substantial electrical system upgrades. Ideally, the building load reduction would be greater than the amount of additional electricity consumed by electrified end uses. Highly efficient system designs should be prioritized to reduce the electrical capacity needed. When electrical system upgrades are needed, they should be paired with other upgrades—such as solar installations and electric vehicle charging infrastructure roll-outs—to reduce their incremental costs.

4. **Develop standardized central systems:** An important design consideration when retrofitting is whether to use existing centralized HVAC and/or domestic hot water systems or to abandon all or parts of these systems. Standardized products should still be developed even in instances where central infrastructure will continue to be necessary.

4 Key Recommendations for the United States

As outlined in the previous sections, the supply of deep energy retrofit packages using panelized facades and combination mechanical systems in the United States is nascent. Despite this, the market need for affordable and timely retrofit solutions is large. In the United States, housing authorities alone have an estimated $26 billion backlog of deferred maintenance (Finkel et al. 2010). As these property owners allocate their limited improvement funds, they need options that can be seamlessly and quickly deployed and that leverage their funds to the fullest extent possible. The technologies highlighted in this report offer solutions that, at scale, could meet those needs in addition to those of market-rate multifamily and single-family housing.

While the technologies and business model outlined in this report should be fostered to create lasting change in the rate of retrofit adoption in the United States, the overall approach to procuring and installing retrofits must transform as well. To catalyze this transformation, Energiesprong has acted as an organizing entity in the Netherlands and was able to understand and address the pain points in scaling retrofits through its overarching, programmatic role. Energiesprong recommends a similar market facilitation approach for the United States so that synergies and scale across markets can be effectively coordinated.

Many of the coordination activities facilitated by Energiesprong required engaging suppliers, cities and states, research institutions, financial institutions, and standard setting bodies, among others, to provide key functions to support the retrofit market transformation. Following are a set of critical activities for catalyzing the U.S. market.

4.1 Market Research and Guidance

- **Conduct a comprehensive typology study:** Although REALIZE has conducted a typology study identifying typical buildings in the Northeast, an additional study should be conducted to determine ownership structure, age, HVAC system, and energy use for all regions in the United States. Cities and states especially can collect more robust information on their building stock to further inform building typology studies.
- **Conduct a market study to understand potential demand for various building facade systems:** Using the results of the typology study, size the potential market for various facade panel solutions and present the findings to the panel manufacturing community. REALIZE has already done this for mechanical systems (Egerter et al. 2018), and this report has served to facilitate conversations within manufacturer R&D and product development teams.
- **Develop regional specifications when asking for facade panels and mechanical systems:** Unlike the Netherlands, the United States has a variety of climate zones, and manufacturers will need guidance on performance specifications across climate zones to ensure performance while enabling standardization.
- **Support manufacturers to act:** Developing a repository of training manuals, process overviews, and design guidelines can help support manufacturers through project implementation.

4.2 Research and Development

- **Focus on high-impact, low-complexity big wins:** Focus on only a few similar climate zones, ideally with large volumes of building stock and only a few highly prevalent building types where there is an opportunity for demand aggregation.
- **Fund demonstrations and field studies of technologies needed to prove technical viability:** To fully convince building owners and occupants, results from field tests should be made publicly available.

- **Encourage development and deployment of a variety of solutions:** One size does not fit all and multiple solutions within a region or climate zone should be encouraged. A number of retrofits will need to be implemented in each U.S. climate zone to understand regional variations and support the build-out of knowledge in regional markets.
- **Invest in internal R&D:** Companies should begin to direct research teams toward innovative new approaches for supplying the renovation and retrofit market, as manufacturers like BGDD did in the Netherlands.
- **Participate in knowledge sharing:** Manufacturers should attend market innovation meetings and working groups to share knowledge, create joint ventures, and collaborate on demonstration projects. DOE recently launched its Advanced Building Construction program[47] and can further serve as a resource and convener for such activities.

4.3 Demand Aggregation

- **Set up building owner and developer meetings:** Cities and states can facilitate and guide workshops in order to socialize the concept of highly standardized deep energy retrofits with owners and ultimately mobilize demand for pre-integrated highly standardized retrofit products.
- **Work with large portfolio owners to aggregate large volumes of demand:** Gathering soft and hard commitments from portfolio owners to put out for bid, using developed performance specifications, will mobilize contractors and manufacturers to produce products to meet demand.

4.4 Policy and Market Signals

- **Develop bold targets for existing building performance and retrofit rates:** By leveraging bold and aggressive building performance targets (through codes or other policy mechanisms) that apply to new and existing buildings, cities and states can help develop demand.
- **Support building owners to act:** Developing a repository of process overviews can help support building owners through project implementation. Additionally, cities specifically can establish programs in which cohorts of building owners can participate. For example, such programs could require net zero or net zero ready retrofit packages to be implemented in order to receive permitting and inspection fast tracking.
- **Align signals from mission-oriented financial institutions:** Preferential terms and rates from mission-aligned financial institutions can greatly enable building owner's abilities to take on these kinds of projects. For example, the Pennsylvania Housing Agency's scoring advantage for Passive House designs when applying for low-income housing tax credits sends a strong signal to building owners that high-performance building improvements are supported and enabled by the housing agency.
- **Work with utilities and other motivated stakeholders to provide gap funding:** Until the industry's learning curve combined with increased volume can achieve cost parity with traditional building systems, sources of gap funding will be needed.

4.5 Workforce Development

- **Empower a cohort of service providers:** As the market scales, a sizeable and knowledgeable community of service providers and installers will be required. Training on the installation and maintenance of high-performance technologies and systems will be critical for ensuring performance and continued adoption.

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[47] For more information, see: https://www.energy.gov/eere/buildings/advanced-building-construction-initiative.

4.6 Conclusion

Overall, there is substantial interest in the types of retrofits that have been developed in the Netherlands. This has been demonstrated through a number of channels, including ongoing building owner interest, which was first tested during the pilot building request for proposal process for the DOE REALIZE pilot project. Furthermore, local and state governments are deploying resources to enable this approach in the market. Examples include a $30-million-dollar RetrofitNY program launched through New York State Research and Development Authority and roughly $7 million awarded by the California Energy Commission to develop a market facilitation platform, including demonstration projects for disadvantaged communities across the state of California. Municipalities such as Boston are also beginning to organize and conduct market-enabling activities to deploy zero emissions retrofits across their building stock. Market enablers have an excellent opportunity to harness this interest and turn it into market action. As discussed in this report, the Energiesprong model serves as inspiration for the United States, but it must be adapted to meet the needs of the U.S. market. This will require all motivated stakeholders to work together to move the industry forward, transform the existing multifamily building stock, and ultimately transform the entire building sector.

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