Exploring the Potential of Factory Installed Solar + Storage for Homebuilding

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Abstract

In recent years, an increasing number of grid disruptions due to intense weather events, natural disasters, and high peak loads resulted in increased interest in energy-resilient homes. Solar + storage (S+S) as an energy resiliency solution can provide continuity, onsite generation, and backup power during critical events. This project explored factory-installed solar plus storage (FISS)[1] to overcome first cost and installation barriers and bring this resiliency solution to scale for single-family affordable and market-rate homebuyers. Guided by the principles of Lean manufacturing,[2] the team explored how factories building high-performance zero energy modular[3] homes can incorporate S+S into their existing construction system while improving quality and productivity and reducing the costs of the resilient energy system.

[1] Factory-installed solar plus storage is the study approach of installing solar panels systems, including a battery in modular homes at the factory.

[2] Lean manufacturing is a production process based on maximizing productivity while minimizing waste.

[3] Zero energy modular homes are homes that combine the cost savings of modular construction with the benefits of zero energy.

Abstract (continued)

The team identified both potential barriers (for example, first cost, permitting, utility interconnection, finished module transportation, and future battery replacement) and value (such as, resiliency benefits, opportunities for utilities, clean energy equity for affordable housing, and new markets for modular factories) of incorporating S+S into factory-built housing. Through a case study and factory information modeling, the team analyzed the FISS approach, which resulted in about 27 percent potential total cost reduction compared with onsite installation. Using the cost reduction results from the case study, the team evaluated the homeowner economics and duration of backup power using the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM)[4] in six locations in the United States. Results showed that in five locations, homeowner net present value (NPV)[5] is positive with long-term, low-interest financing through a mortgage. The SAM analysis showed in almost all cases, the S+S system could power 25 percent of the electricity needed in a home for 4 days, and under some scenarios, up to 100 percent of the load for 4 days. Findings from this study show S+S is a viable backup power source during grid outages and supports the creation of a high-performance factory to produce resilient homes that can be adopted at scale, with reduced cost by integrating S+S with prefabricated modules guided by lean manufacturing[6] principles.

Introduction

The aim of this study was to create a resilient home product that can be adopted at scale, with reduced cost by integrating S+S with prefabricated modules guided by lean manufacturing principles.

Significance of the Work

In the past few decades, more frequent and intense weather events, higher peak loads, and natural disasters that create power outages have increasingly tested the electric grid in the United States. Without power, businesses, industry, and schools are disrupted, leading to economic losses and health and safety risks. To date, most aspects of resilient design have focused on construction methods that can withstand severe weather with high winds or flooding. Partnering with modular factories that already build high performance zero energy modular homes to incorporate solar + storage (S+S) into their existing construction system will provide energy resilience, continuity, and backup power during critical events (Green Mountain Power, 2018). In 2019, the U.S. Department of Housing and Urban Development (HUD) tasked Home Innovation Research Labs with creating a set of Residential Resilience Guidelines for Builders and Developers and identified the need to include onsite renewable power generation, grid independence, and grid interaction as resiliency measures (Home Innovation Research Labs, 2019). Factory-installed solar plus storage (FISS) has the potential for broad adoption if promoted by voluntary resiliency standards, such

[4] System Advisor Model is a free technology-economic software developed by NREL to model performance and financial estimates of energy cost for grid-connected photovoltaic systems.

[5] Net present value is a method to calculate the current value of a future stream of payments from an investment.

[6] Lean manufacturing is a production process based on maximizing productivity while minimizing waste.

as FORTIFIED™[7] and RELi.[8] Shorter process for customers to research, financing, permitting, and lengthy applications. If factories included S+S as an option in standard home designs, FISS would reduce the decisionmaking complexity of the process from a customer perspective, help facilitate the integration of resiliency measures in home design under a controlled environment, while also reducing costs and providing continuity, onsite generation, and support during critical events.

How this Effort Will Change Homebuilding

Current research efforts show that inefficient construction processes are a major factor in the high cost of construction (Feldman et al., 2020). The homebuilding process needs to change, and factory-built homes are already well positioned to achieve more efficient processes by design and construction. Factory-built homes can also help facilitate the integration of resiliency measures (for example, S+S) under a controlled environment, leveraging integrated design, using assembly line techniques and factory employees (trained, scheduled, and managed by one employer). According to a recent report by McKinsey & Company, prefabricated assembly of modular buildings has demonstrated up to 20 percent cost savings and 50 percent construction time savings and is being looked to as a proven "affordability through innovation" method to increase productivity and significantly reduce construction costs (Bertram et al., 2019). Redesigning factory processes according to lean manufacturing principles while integrating S+S can reduce inefficiencies in the production process, minimizing those initial costs. Currently, modular factories, the solar industry, or storage providers do not widely understand knowledge on FISS and its lean benefits. New quality control methods can support FISS at the plant. As construction costs decrease, energy-efficient and resilient homes will become more desirable and widespread.

This project aims to analyze the economic benefits of FISS and explore the market to create a resilient home product that factories can adopt at scale, with reduced cost by integrating S+S with modular construction guided by lean manufacturing principles. Results from this project set forth a new strategy for resilient construction to all-electric zero energy modular homes and redesigning resilient power systems from backup diesel generators to S+S.

Anticipated Changes Needed To Bring FISS to Scale

Business as usual in the construction and homebuying processes will need to change to support the widespread adoption of FISS. Streamlining and standardizing building codes, inspection, and permitting processes will be crucial for the market adoption of S+S technologies. In addition, homeowners need access to mortgages that meet the payment schedules of modular housing and appraisals that recognize and understand the value of S+S. Utilities will need to support S+S with interconnection and net metering. The critical need is for existing and new factories to be willing to build a zero-energy standard and offer FISS as a standardized product to homebuyers.

[7] FORTIFIED is a voluntary resilient standard that the Insurance Institute for Business & Home Safety developed and designed to be resilient to hurricanes, high winds, and hail.

[8] RELi (Resilience Action List) is a voluntary resilient standard developed to increase adaptability and reduce sensitivity to hazards for building occupants.

Why HUD Funding Was Needed

This project builds on past HUD funding to further lean manufacturing principles in offsite construction, and more funding is required to explore expanding resilient homes to include resilient power systems. Unlike other federal agencies, HUD funding supports applied research in the cross section of housing, energy, affordability, resiliency, quality, and labor safety. Outcomes are actionable, and evidence-based recommendations to enable the homebuilding industry to work toward The HUD Offsite Construction Research Roadmap[9] include S+S in voluntary resiliency standards financing to promote and support S+S in new homes. The study contributes to a better understanding of the usability of resilient technologies and eases the transition toward implementing resiliency criteria into every home builder company's culture. It also promotes more efficient and cost-effective operation within the factory homebuilding industry to incentivize integrating S+S within production while minimizing total costs and lead time. Overall, a new lean-centric strategy was established to manage and operate modular homebuilding and disseminate knowledge on lean pathways for integrating S+S into factory-built housing to home builders and the solar workforce.

Market Trends and Resiliency Benefit of FISS Homes

Through interviews and market research, the team identified several key value propositions for incorporating S+S into factory-built housing.

1. **Homeowner Resilience Benefits.** In many cases, if the first cost of the system is rolled into a mortgage, lower utility bills make it a cost-effective investment for the homeowner. The customer economic analysis did not include a value of the resilience benefit of backup power during outages. Insurers would generally be interested in opportunities to quantify the value of not losing power or restoring power quicker after severe disasters. Claims related to power outages could include food spoilage or damage from frozen pipes. Some insurers may consider homes still habitable even during power failures, but additional claims may arise for hotel stays while waiting for power and heat to return. Power continuity is important for reducing effects on the home, increasing habitability, and supporting claim reduction. Insurance companies, therefore, would likely be interested in learning how onsite energy production can drive down value of claims.

2. **Opportunities for Utility Companies.** There is potential value in deploying residential S+S for utility companies. Battery deployment can reduce peak demand, deferring or eliminating capacity investment; provide frequency regulation; and ease system integration of renewables.[10] Having more utilities embrace S+S for the residential sector with incentives will be important to bring the solution to scale. More work should be done connecting factories to utility companies with existing programs, making them aware of incentives and standard

[9] The HUD Offsite Construction Research Roadmap is at https://www.huduser.gov/portal/pdredge/pdr-edge-trending-072622.html.

[10] For more information, see https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-residential-energy-storage-could-help-support-the-power-grid.

designs to island a home during outages. Vehicle-to-grid charging is another opportunity for utility companies to harness to provide power in post-disaster scenarios.

3. **Clean Energy Equity and Affordable Housing Applications.** Housing and energy advocates have a broad cross-sector interest in zero energy modular as a potential solution to the housing crisis, and FISS is a natural extension that would help support decarbonization and equity goals.

4. **Providing New Markets for Modular Factories.** Creating standardized, repeatable home designs with S+S that meet resiliency standards such as FORTIFIED and RELi could help support factories in demonstrating the high quality of the housing product and directly addressing misconceptions in the market. Because FORTIFIED requires third-party verification, it would be a selling point to potential customers and retailers. Modular housing lends well to incorporating resilient design features, such as roof deck sealing, protecting attachments, and paying attention to load paths, due to their protected environments and repeatable processes.

Key Markets for a FISS Solution

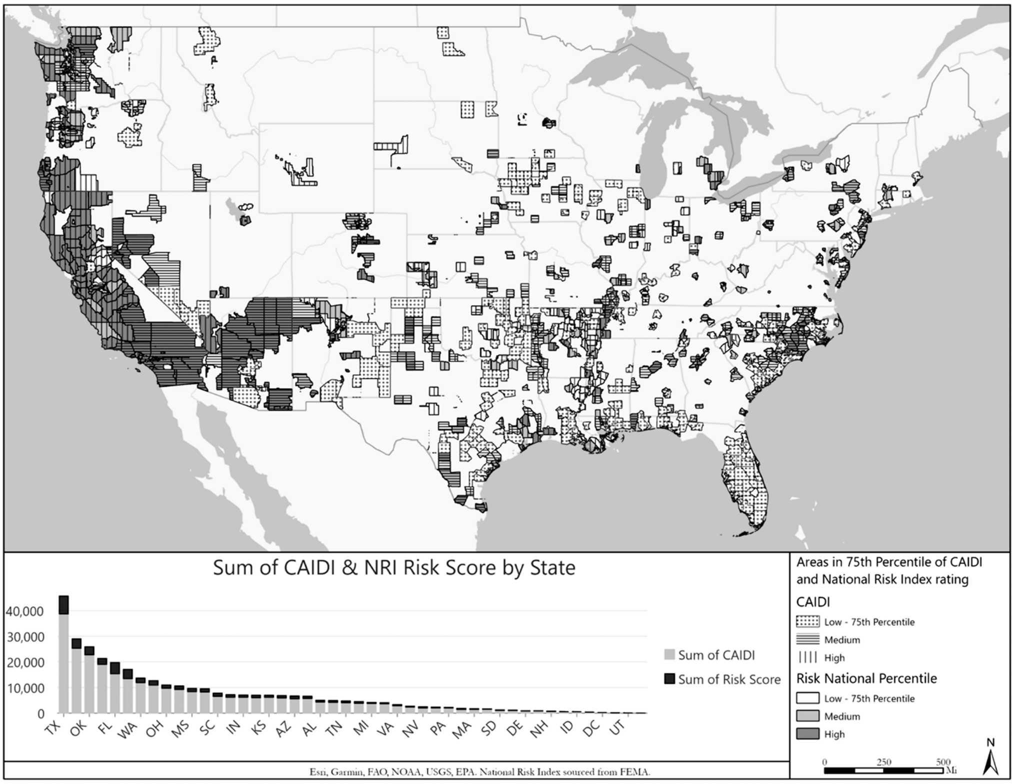
Locations with frequent power outages and a high risk of natural disasters are markets that would benefit from S+S. Modular factories conducting market research will want to consider resilient design elements to evaluate the appeal of these features to potential customers, while gaining insights into the needs for energy resilience in markets that they already serve.

Energy Resilience and Climate Risk

Although frameworks have been recently proposed, a metric that measures residential utility energy resilience has yet to be determined. The U.S. Energy Information Administration reports annual utility reliability data through metrics of interruption duration and frequency. The Customer Average Interruption Duration Index (CAIDI) takes the sum of all customer interruption durations divided by the total number of customer interruptions to determine the average restoration time for each utility. The National Risk Index that the Federal Emergency Management Agency (FEMA) developed incorporates natural hazards risk (measured as the annual expected loss of building value, population, or agricultural value), social vulnerability (measured by demographic characteristics to measure susceptibility of social groups to adverse effects of natural hazards), and community resilience (demographic characteristics as a measure of a community's ability to prepare for, adapt to, withstand, and recover from a disaster) to establish a baseline score for relative risk (FEMA, 2021). When the FEMA National Risk Index data are joined with CAIDI duration data from 2020, results reveal that a significant number of areas could benefit greatly from resilient power systems, as exhibit 1 shows.

Exhibit 1

Areas in 75th Percentile of CAIDI Outage Duration and National Risk Index Rating



CAIDI = Customer Average Interruption Duration Index. NRI = National Risk Index.
Note: Graph shows combined totals of each metric by state.
Source: FEMA National Risk Index for National Hazards

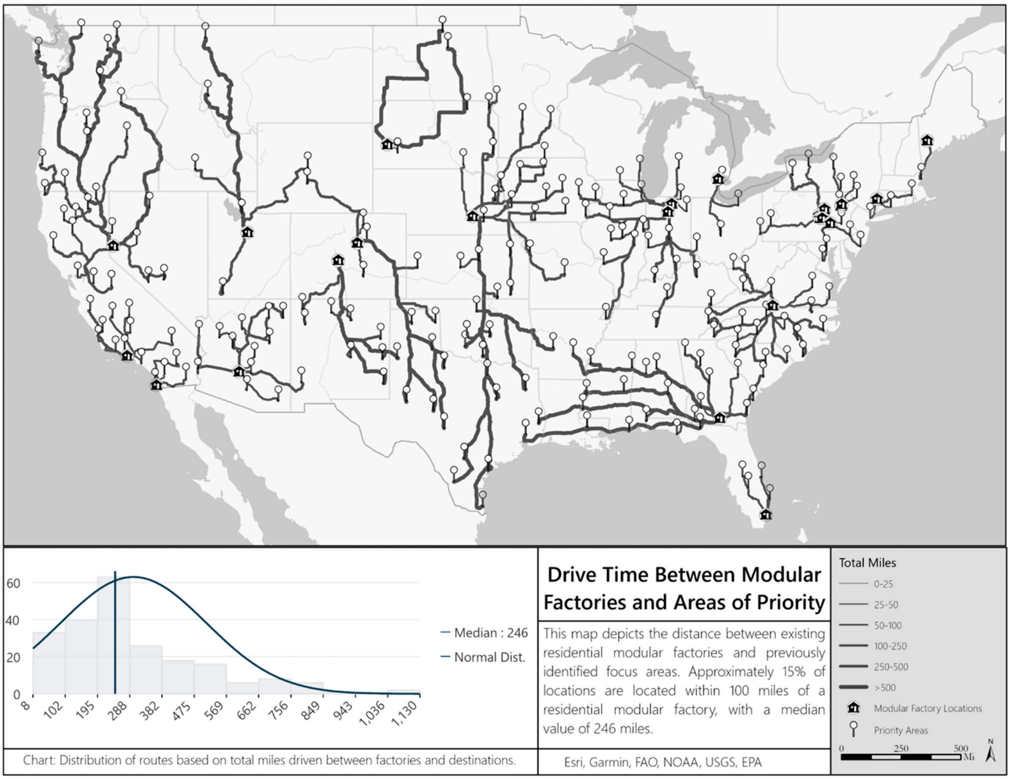
Nearly every state in the continental United States has at least one county in the 75th percentile of risk and CAIDI outages. This number of outages is without the inclusion of major event days that are projected to increase as global temperatures rise. Areas that are at high risk in the National Risk Index and in outage duration are concentrated in coastal areas, mostly on the west coast and Pacific Northwest. These data indicate the need for energy power backup systems across the United States and potential for mitigating risk and supporting vulnerable populations through resilient design features.

Where Factory-Built Housing Needs To Scale

Even if current modular factories started incorporating S+S and other resilient design features into their products, gaps of service would be likely for the priority areas noted previously. Most residential modular factories are near the coasts; however, significant gaps are still in service territories. Although not a requirement for a modular home to be delivered in a day, costs may become prohibitively expensive as distance from factories increases. In addition, some factories may limit deliveries to locations within 100 miles (exhibit 2).

Exhibit 2

Driving Distance Between Modular Factories and Identified Priority Deployment Areas



Source: Modular Building Institute

With this limitation, existing residential modular factories today could service less than 15 percent of identified priority areas. Notably, this limitation does not account for unrealistic delivery scenarios that geographic factors pose, such as deliveries crossing over mountain ranges. To bring FISS to scale, more factories will be needed, calling for a joint effort of investments from the housing, energy, and economic development sectors.

Economics of FISS Solution

Using the cost reduction results from the FISS Case Study section, the team evaluated single-family homeowner economics and duration of backup power in six locations in the United States. The locations were chosen to examine how different solar resources, electric consumption, and rates affect the financial results and performance during outages. The locations cover all regions and International Energy Conservation Code climate zones in the continental United States, and four of the five high-priority states called out in the Advanced Building Construction Collaborative *Market Opportunities and Challenges for Decarbonizing U.S. Buildings* report (Fisler et al., 2021). All the locations chosen are in the 75th percentile for outage risk, quantified with CAIDI scores and National Risk Index Risk Scores, as the Energy Resilience and Climate Risk sections discuss.

To estimate home energy consumption, the team used Open Studio's Parametric Analysis Tool with Open Studio-HPXML measures to run Energy Plus simulations. The prototype home was modeled to an all-electric, high-performance specification in six different climate zones. Exhibit 3 shows the locations, climate zones, modeled electricity consumption, and modeled solar photovoltaic (PV) generation.

Exhibit 3

Locations Used for Customer Economic and Resiliency Analysis with Electric Consumption and Photovoltaic Generation Data

Location	IECC Climate Zone	Consumption (kWh)	PV Capacity (kWDC)	PV Generation (kWh)	PV Share of Use (%)
Houston, TX	2A	7,764	5.4	7,598	98
San Bernardino, CA	3B	7,172	4.3	6,357	89
Philadelphia, PA	4A	8,064	6.0	8,608	107
Bellevue, WA	4C	7,336	7.0	7,770	106
Wayne, MI	5A	9,320	7.3	9,887	106
Smallwood, NY	6A	8,695	7.0	9,713	112

IECC = International Energy Conservation Code. kWh = kilowatthour. kW_{DC} =kilowatt direct current. PV = photovoltaic.

Sources: Consumption—HPXML model and zero energy modular home; PV capacity—calculated for 100 percent of load; PV generation—National Renewable Energy Laboratory System Advisor Model; PV share of use—calculated by the authors

The team used the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) to size the batteries to meet the modeled energy use and to evaluate homeowner economics by running scenarios that tested the sensitivity of financing, first costs of S+S, effects of the climate zone on solar resources, electric consumption, and electric rates to understand the effect on financial results and performance during outages. Exhibit 4 shows the inputs to SAM.

Exhibit 4

Parametric Inputs

Input Variable	Values Used	
Installed cost ($)	Average, average minus $5,427, average minus $10,126	
Location	Informed solar resource, consumption, electric rates	
Photovoltaic capacity (kW_{DC})	Varied by location 4.3 to 7.3	
Battery capacity	13.5 kWh_{AC} and 5 kW_{AC}	
Critical load percent of total load	25%, 50%, 75%, 100% of total electric load	
Loan type	Personal Loan	Mortgage
Tax deductible interest	No	Yes
Loan term (years)	15	30
Loan rate (%)	5	3

kW_{AC} =kilowatt alternate current. kW_{DC} = kilowatt direct current.

The analysis showed that the most significant driver of positive net present value (NPV) is long-term, low-interest financing through a mortgage. For homeowners, a positive NPV would be attained by rolling the first cost of FISS into a mortgage in California, Michigan, New York, Pennsylvania, and Texas. No cases of positive NPV were associated with 15-year personal loan financing in any of the locations. Offsetting electricity with solar PV in states with high-cost electric rates increases NPV for the customer and provides a lower NPV for customers in states with low-cost electric rates. For example, in Washington, a state with low-cost electricity rates, homeowners would not have the benefit of positive NPV, even when rolling the first cost of the FISS into a mortgage. A final consideration is solar resources. Locations with higher solar resources and production can increase NPV even in states with lower utility costs, like Texas.

To evaluate how long the S+S system would support the electric loads during an outage, the team modeled a range of critical load percentages (exhibit 5). Under this scenario, the results show the probability of the battery being able to support the electric load for an outage at any time of year and time of day, as well as the mean hours the battery lasts across the simulated outages.

Exhibit 5

Resiliency Results from System Advisor Model Analysis: Likelihood of the Battery Lasting Through a 4-Day Outage and the Mean Hours of Autonomy for Four Scenarios of Regular Energy Consumption

State	IECC Climate Zone	Probability of Surviving 4-Day Grid Outage (by Percent of Load)				Mean Hours of Autonomy (by Percent of Load)			
		25%	50%	75%	100%	25%	50%	75%	100%
TX	2A	97%	76%	28%	5%	3,236	590	79	31
CA	3B	100%*	80%	33%	5%	8,760*	633	98	34
PA	4A	94%	69%	30%	10%	3,486	1,155	96	42
WA	4C	86%	59%	39%	13%	3,046	972	150	42
MI	5A	83%	57%	33%	14%	2,510	963	112	46
NY	6A	89%	64%	35%	13%	3,103	1,403	112	45

IECC = International Energy Conservation Code.
** SAM did not find an outage that the load would not be met when evaluated during a 14-year horizon.*
Source: National Renewable Energy Laboratory SAM

The SAM analysis showed that in almost all cases, the S+S system could power 25 percent of the electricity needs in a home for 4 days, and under some scenarios, up to 100 percent of the load for 4 days.

FISS Case Study: KBS Builders' Factory

A case study method was used to test the FISS approach, using data from the existing plan layout, material handling system, and operations of the project partner, KBS Builders, Inc. The team performed a comprehensive time study to help understand current productivity and identify opportunities to improve operations, reduce downtime at or in-between stations, and add new activities without undermining the current weekly productivity. The team used simulation modeling tools to replicate the flow of materials and discrete activities at and in-between stations (Podder et al., 2022). To study the current conditions in KBS Builders' factory, the team followed a data collection strategy to include activity durations using a combination of expert interviews, manually documented time stamps from travelers, and data-collection methods using video data obtained from the factory. Key datasets included factory-built and onsite schedule, rough-in stage details, number of workers involved in each station, factory production rate (on average), workforce composition (trades, labor, and other salary employees), factory photos and documentation of visual inspections, and information pertaining to spatial aspects of the construction progress. These datasets enabled the team to perform a comprehensive time study to help understand the existing conditions and identify early opportunities to improve weekly productivity, reduce downtime at or in-between stations and bays, and add new activities without undermining the current weekly productivity.

Onsite Solar + Storage Installation: Current Approach and Challenges

Most of onsite S+S installations are retrofits. In 2020, retrofitting accounted for 72.6 percent of all residential S+S systems installed (Grand View Research, 2021). Results of the study showed that retrofits are less efficient than when S+S is integrated into new construction, thus construction costs could be reduced (O'Shaughnessy et al., 2019). The team evaluated the onsite S+S installation approach via interviews from field professionals. Onsite S+S installation requires various trades and a solar subcontractor to coordinate material delivery and installation activities to each site. Typically, all equipment and materials are handled manually, thus reducing the efficiency of the installation and affecting the safety of workers. Ladders and ladder lifts are used to bring material on the roof and workers must wear safety harnesses. A need for solar-ready design houses exists (Labik et al., 2022). If the system is completely retrofitted, post-installation inspections are usually prolonged and can cause the inspectors to withhold the certificate of occupancy, due to the installations not meeting local code. Such issues lead to expensive onsite rework, decreases in efficiency, and prolonged lead time.

Offsite Solar + Storage Installation: FISS Approach

The offsite S+S installation moves most of the site work into the factory.

Baseline Process Simulation Model

KBS Builders' weekly production target is eight modules; however, due to perceived bottlenecks and downtime, the factory has been able to achieve an average of five to seven modules. KBS Builders have expressed strong interest in identifying opportunities to consistently achieve at least eight modules per week, while adding the required activities related to S+S installation. In this study, the team chose the weekly production rate (that is, number of modules completed per work week) as the key performance indicator to evaluate different scenarios against the current market trend of onsite S+S installation. Based on the data collected from KBS Builders, the team created a baseline process simulation model in AnyLogic™ software. The baseline process simulation model acts as a digital twin of the real-world physical factory, because it accurately reflects the two-dimensional floor plan layout of the KBS Builders, the factory construction schedule, the workers and resources allocation in each station, the weekly productivity, and the work time in each station.

Estimated Solar + Storage Installation Time Data

Offsite integration occurs in a controlled factory environment. This setting ensures better coordination of standard installation procedures and resources in a controlled environment.

In the factory, installers can perform their work at a predetermined station suitable for activities related to S+S installation, including integration of small, distributed home batteries (see exhibit 6 for detailed installation time and resources needed).

Exhibit 6

Solar + Storage Related Activities with Installation Times

Activity with Location and Sequence	Production Type	Description	Number of Workers	Activity Time (in Hours)
Solar ready (Rough Electrical and Plumbing–Station #5)	Installation activity	1” PVC from mech room to roof	2	1
	Installation activity	1” PVC from mech room to electrical main	2	1
	Installation activity	2” PVC from mech room to electrical main (for battery)	2	4
	Installation activity	Conduit and wiring to belly or gable end	2	3.5
Preset solar roofing (Feeder Roofing Station–on the floor)	Installation activity	Solar deck installed on roof	1	2.2
	Installation activity	Solar feet installed on roof	2	2.3
	Installation activity	Solar rails installed on roof	3	
Solar roof set (Roof Set and Exterior Insulation–Station #7)	Roof set activity	Solar roof set on WIP module	NA	0.50 (same as typical roof set)
Post-set solar roofing (on top of the module)	Installation activity	Microinverters installed on roof	3	6.5
	Installation activity	Solar panels installed on roof	3	
Home battery install (Electrical Hookups–Station #14)	Installation activity	Battery in mech room	2	2.7
	Installation activity	Battery gateway	2	2.6
	Installation activity	Paneling for meters and disconnects on gable end	2	2

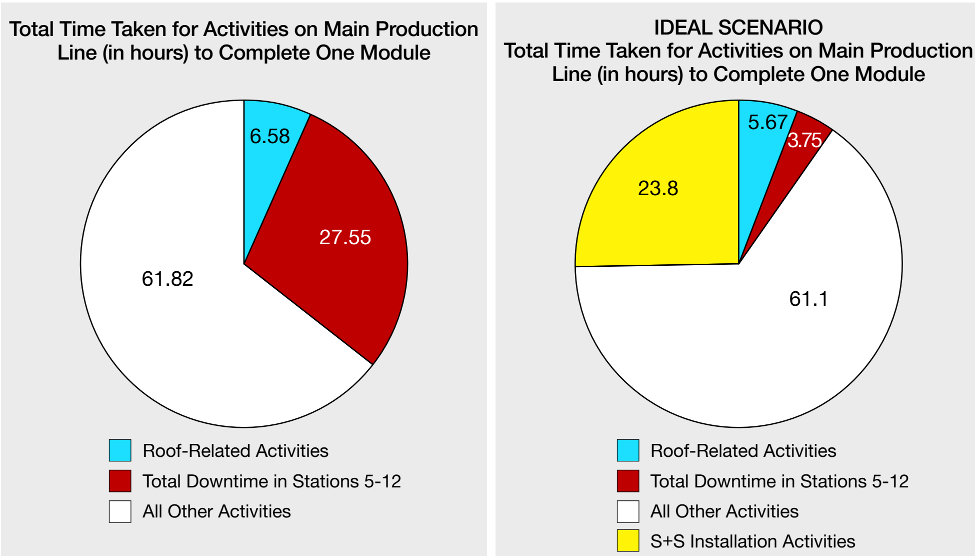
NA = not applicable. PVC = polyvinyl chloride. WIP = work in progress.

Comparison Analysis and Results

The team simulated an ideal FISS scenario within AnyLogic™, leveraging the baseline process model. The major learning outcome from exhibit 7 is that the new activities related to S+S installation can be added to the main production line without affecting the weekly production rate of eight modules per week. Such an ideal scenario is only possible after stations 5 through 12 undergo line balancing strategies that include reorganization of roof-related activities. See the Conclusions and Discussion sections for detailed results.

Exhibit 7

Total Time Taken To Complete Activities for One Module



Note: the baseline is shown on the left, and the ideal scenario is shown on the right.

Cost Analysis of FISS

The team used the data from the solar vendors and installers interviews and NREL 2020 Solar + Storage Cost Benchmark to model the cost of the onsite installation approach (Feldman et al., 2020). The FISS cost was modeled using these costs and the simulation output.

Onsite Installation Cost Analysis

The cost analysis assumes a solar-ready home with 7.12 kW system and Tesla Powerwall 2 battery (13.5 kWh, 5kW rated output) installed on site. Contractors provided an onsite installation cost averaging about $37,824, with the cost breakdown in exhibit 8.

Exhibit 8

Onsite Installation Cost Breakdown

Cost Component	Cost ($)
Hardware	18,103
Permitting, inspection, and interconnection	825
Installation cost	18,896
Total cost	**37,824**

The team used NREL's 2020 Solar + Storage Cost Benchmark, which breaks down the cost into $/W$_{DC}$ (dollar per Watt of direct current) to further break down the installation cost into each type of soft cost components (Feldman et al., 2020). In this analysis, the same 7.12 kW system was used. The specific assumptions and costs/W$_{DC}$ are in exhibit 9.

Exhibit 9

Assumptions of Cost Model

Cost Component	Modeled Value	Description
Net profit	17%	Applied to hardware, installation labor, sales and marketing, design, PII
Sales and marketing (customer acquisition)	$0.67 / Watt	Advertising, sales pitch, contract negotiation, customer interfacing
Engineering fee	$100	Engineering design, professional engineer-stamped calculations, and drawings
PII	*Given by contractors*	Completion of applications, fees, design changes, field inspection
Overhead	$0.28 / Watt	Rent; building, equipment, staff expenses
Installation labor	*Calculated*	Time study data
Installation labor burden	18%	Workers' compensations, federal and state unemployment insurance, FICA, builder's risk, public liability, applied to installation labor cost
Sales tax	5.1%	5.1% of cost of equipment
Supply chain cost	5%	5% of cost of equipment; Shipping, handling, inventory
Electrical BOS	$0.28 / Watt	Conductors, switches, combiners and transition boxes, conduit, monitoring system, fuses, breakers
Structural BOS	$0.08 / Watt	Flashing for roof penetrations, rails and mounting
Equipment	*Given by contractors*	

BOS = balance of system. PII = permitting, inspection, and interconnection.

The contractor gave the actual costs of the hardware and the permitting, inspection, and interconnection (PII). Other soft cost components were found by using the output of the ideal scenario (including S+S installation activities) model. Net profit paid to the contractor is modeled as a fixed margin of 17 percent that is applied to all hardware, labor, sales and marketing, design, and PII fees, resulting in $4,699. Sales and marketing for the onsite approach were modeled as 0.67 $/WDC, resulting in $4,770 and accounting for advertising, sales pitch, contract negotiation, and customer acquisition. The installation labor was found to be $2,492 with a labor burden of $449. Once all soft costs were determined, the team validated the results with subject matter experts.

FISS Approach Cost Analysis

The team followed the same assumptions and approach, based on soft cost savings, to calculate factory installation cost for each system component. First, if the system is installed in the factory by using the existing workforce, the net profit paid to the contractor is removed, resulting in $4,699 savings per system installed. Furthermore, sales and marketing costs of the S+S system are significantly reduced, mainly due to the system being advertised with the house, thus eliminating the need for extra marketing, contract negotiation, or extra customer acquisition. The sales and marketing cost, based on field professionals' interviews, was modeled as 0.15 $/W$_{DC}$, resulting in savings of $3,702 per system installed. In the FISS approach, the overhead cost of the S+S system is built into the final house cost, which subject matter experts estimated results in a 30-percent reduction. Through the simulation, the team found the installation labor cost to be on average $1,538 per system, with an installation burden of $277, yielding savings of $1,126 per installed system. The FISS approach resulted in a total savings of $10,126 per installed system—about 26.77 percent potential cost reduction compared with onsite installation.

At this point, the manufacturer must decide how to allocate the savings realized through the FISS approach—either keep savings as profit or pass on the savings to the customer. The team chose to model three potential scenarios for the customer economics analysis: (1) Manufacturer keeps total savings as profit (for example, $0 of the savings are passed on to the customer), similar to the current onsite approach; (2) Manufacturer keeps the factory installation savings and the rest of the savings, about $5,427, are passed on to the customer; and (3) All the savings, about $10,126, are passed on to the customer.

Exhibit 10 shows the S+S cost breakdown for all three scenarios.

Exhibit 10

Solar + Storage Cost Breakdown

	Onsite Approach	Factory Installation, Profits Kept		Factory Installation, Maximum Price Reduction	
Cost Component	**Cost ($)**	**Cost ($)**	**Savings ($)**	**Cost ($)**	**Savings ($)**
Net profit	$4,699	$4,699	$0	$0	$4,699
Sales and marketing (customer acquisition)	$4,770	$1,068	$3,702	$1,068	$3,702
Engineering fee	$100	$100	$0	$100	$0
Permitting, inspection, interconnection	$825	$825	$0	$825	$0
Overhead	$1,994	$1,396	$598	$1,396	$598
Installation labor	$2,492	$1,538	$954	$1,538	$954
Installation labor burden	$449	$277	$172	$277	$172
Sales tax (of cost of equipment)	$923	$923	$0	$923	$0
Supply chain costs (of cost of equipment)	$905	$905	$0	$905	$0
Electrical BOS	$1,994	$1,994	$0	$1,994	$0
Structural BOS	$570	$570	$0	$570	$0
Hardware	$18,103	$18,103	$0	$18,103	$0
Total savings			**$5,427**		**$10,126**
Total cost (system installed)	**$37,824**	**$32,397**		**$27,698**	

BOS = balance of system.

Conclusions

The FISS approach resulted in a total savings of about 26.77-percent potential cost reduction compared with onsite installation. In addition, implementing the ideal scenario would mean completing eight modules per week with integrated S+S. Solar ready activities, post-set solar roofing activities, and home battery installation activities use 86.39 percent of the observed downtime in stations 5 through 12, where the remaining downtime can be available for idle time or buffer time by design. Furthermore, the main production line is balanced and can continuously achieve the weekly production target of eight modules per week. Introducing innovation into homebuilding results in a different set of challenges to management, the following list identifies these challenges and potential solutions that managers responsible for implementing new technology must surmount practical guidelines for factories to design and construct affordable S+S homes. The recommendations in exhibit 11 help to ensure the efficient and effective integration of S+S installation.

Exhibit 11

Recommendations (1 of 2)

Houses Should Be Solar-Ready Designed Early in the Design Phase

- **Product Design.** Using lean product design can eliminate waste in production before it happens.
- **Net Zero Emission (NZE) Goals.** For companies to achieve aggressive NZE goals, clear direction from the client must be given, and teams must fully embrace the directive.

Production Line Needs To Be Tailored for Solar + Storage Installations

- **Balance of Systems.** New activities related to solar + storage installation can be integrated into the main production line without affecting the weekly production rate after downstream stations undergo line balancing strategies, leading to 100 percent utilization.
- **Reorganization of Roofing Activities**
    - Reorganizing relevant roofing activities to the feeder stations that run parallel will reduce travel distance and time.
    - Moving the solar roofing activities to the floor closer to the roof build as an extension of the feeder station can reduce the total time for related activities by 50 percent and mitigate existing bottlenecks.
    - Preroof set activities: Mounting and solar decking activities can be moved to the floor, immediately after solar roofing.
    - Post-roof set activities: Solar photovoltaic install activities can occur after the roof is set; activities can be moved upstream, on the floor, closer to roof build station.
    - Home battery installation activities: Small, decentralized home battery can be installed after the interior paint activities.
- **Minimizing Excess Processing Time.** Solar-ready activities can be performed along with electrical roughing, and workstations with similar activities can be combined, allowing for workers and resources to move between the stations.

Workforce Strategy Needs To Be Developed

- **Workforce Strategy.** To reach production objectives more quickly and efficiently, facilities must adopt a lean-centric workforce strategy. This strategy could include multiskilling existing workers, hiring a new department focusing only on solar + storage related activities, or using a subcontractor to install the system.
- **Maintain Skilled Workforce.** Identify opportunities to upskill existing workforce and understand trade-offs for involving solar + storage subcontractors in performing the new activities.

Exhibit 11

Recommendations (2 of 2)

Quality Control Inspection Must Be Tailored for Solar + Storage Installation

- **Quality Control.** Developing a comprehensive quality control strategy for each solar + storage related station to audit the work eliminating waste and reduce costs caused by defects.

Supply Chain, Long-Term Storage, and Staging Areas Need To Be Established

- **Supply Chain.** Procure solar + storage components and systems from a regional supply chain.
- **Storage and Staging Area.** Expand current factory floor to add a storage area for solar + storage components and systems.
    - Benefits of adding long-term storage and staging areas include limiting travel distance and material handling and decreasing the probability of damage to materials due to handling and exposure.

Multiple stakeholders benefit from the design solution that FISS provides in exhibit 12.

Exhibit 12

FISS Design Solution

For Homebuilders

- Provides additional benefits for customers that are marketable, including quality, safety, resiliency, energy efficiency.

For Homeowners

- Provides resilience, comfort, safety, potential financial benefits.

For Policymakers

- Product can be mass-produced, support disaster recovery, support sheltering in place, continuity in vulnerable populations.

For Utilities

- Product can create grid-interactive homes that are able to participate in utility programs and support grid functions.

As this analysis notes throughout, despite barriers, a growing interest is in scaling S+S as a resiliency solution and scaling modular housing to address industry needs and gaps. Great potential exists to scale modular housing in the United States to support resiliency and efficiency. Driving adoption of FISS in the residential new construction market is not simple. The new construction industry is chronically fragmented with many players across design, construction, supply, and demand. The industry is largely the same as it was 100 years ago—same business models and profit margins that require risk aversion. Increasing the deployment of S+S will require a combination of technology innovation, workforce training, demand aggregation and supply development, and a cross-sector approach. The following recommendations focus on what could help further scale this solution to reach one million customers during the next 10 years.

- Mortgages that meet payment schedules of modular.
- Appraisals that recognize value of S+S.
- Existing and new factories willing to build to a zero-energy standard and offer FISS as a product.
- Utility companies that will support S+S.
- Homeowners that understand value proposition.
- Standardization of building code.

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