Assessing the New Home Market Opportunity: Case Study and Cost Modeling for Solar and Storage in 2030

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Minahil Qasim, and Matt Miccioli

National Renewable Energy Laboratory

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Executive Summary

Residential solar and storage markets are growing in the United States. With approximately 1 million new homes constructed every year, this represents a significant opportunity for solar and storage installations. Some homebuilders have begun to build new homes with solar and storage included as a standard offering. However, it is not clear how solar and storage are incorporated into the new construction process and at what cost. Further, it is unclear what barriers or opportunities exist in scaling this model nationwide.

To fill this gap in the literature, we conducted a case study of Mandalay Homes' new solar and storage community in Arizona to gather lessons learned. From this foundation, we generated a set of pathways to reduce installation costs and expand solar and storage market penetration in this sector. To model existing and 2030 solar and storage costs, we used the National Renewable Energy Laboratory's (NREL's) bottom-up cost model. This modeling was further informed by 12 interviews conducted with new homebuilders, solar contractors, and other subject matter experts.

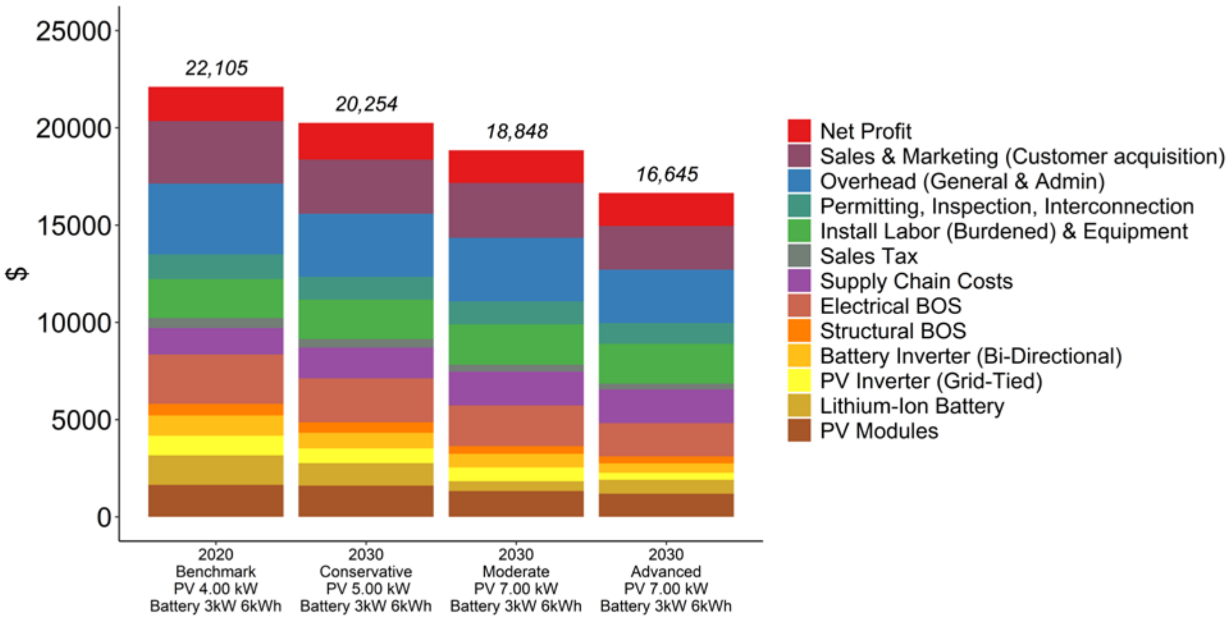
Our case study analysis generated three key considerations for homebuilders, including:

1. Educating local permitting, inspection, and, in some cases, utility officials on solar and storage products, designs, and code-compliant building practices may be required. The need for education may decline as more local governments and utilities review and approve solar and storage projects.

2. Incorporating solar and storage systems into the homebuilding process can add complexity and related coordination challenges. This does not need to result in home construction delays, but can result in costly contractor "dry runs" to and from construction sites.

3. Deploying solar and storage at the time of new construction has significant economies of scale, which can improve the value proposition of the systems.

The case study, extant literature, and interviews were used to model both existing and future solar and storage installation costs at the time of new construction. Here, we find three key cost reduction opportunities, relating to solar and battery storage hardware, customer acquisition, and overhead. If future contractors can maximize the cost reduction opportunities outlined here, residential new construction costs could decline by 8%–25% by 2030, depending on the modeled scenario (see ES Figure 1).



ES Figure 1. Comparison of current and 2030 residential Photovoltaic (PV) plus Alternating Current (AC) coupled storage costs

Though we expect costs to decline through 2030, it is unclear which of these scenarios may ultimately appear. Interviewees identified a variety of barriers across each cost category that could temper the savings shown here.

At the same time, interviewees described several pathways to scale the new construction solar and storage market, beyond installation cost savings. Interviewees confirmed that changes in financing, rate design, resilience policies, deployment mandates, and distributed energy resource (DER) aggregation could all support more market adoption than is seen today. These findings suggest that there are significant opportunities to expand new construction markets, and this research can serve as a baseline to assess progress in this segment through 2030.

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1 Introduction

In 2020, the United States had a cumulative 19 gigawatts (GWdc) of residential solar photovoltaic (PV) capacity (Wood Mackenzie, 2021c). A growing percentage of these solar installations are being paired with battery storage, from 0.1% in 2015 to 8.1% in 2020 (Barbose *et al.*, 2021). In addition, the residential PV-plus-storage market is expected to increase twelvefold, from 180 MW in 2018 to 2,181 MW in 2023 (Wood Mackenzie, 2019).

Market interest in pairing batteries with solar is growing, given economic, resilience, and policy mandates incentivizing its use. In some states, like Hawaii, solar paired with storage is economically attractive; the battery can maximize the value of solar given required time-of-use (TOU) and/or demand charge rate structures, as well as greatly expediting system interconnection (Hawaiian Electric, 2021). Even where rate structures do not incentivize storage, many customers are opting for adding battery storage to their solar systems to provide backup power during natural disasters or voluntary electricity shutoffs (Clean Energy Group, 2019). Finally, some states are considering or have adopted policy mandates to require solar and storage systems. For example, California will require certain new buildings (i.e., commercial and multifamily buildings) to incorporate solar and storage in 2023 (CEC 2021).

Even so, the cost of installing residential solar and battery storage projects remains a barrier to adoption nationwide. For example, a typical residential retrofit solar and storage system ranges from \$26,153 to \$37,909, 38% to 100% higher than a standalone PV system, depending on the size of the battery (Feldman *et al.*, 2021). These cost barriers also apply to new construction, but it is possible that installing solar and storage could cost less in this case, given that these systems can be installed across a new subdivision in succession, as opposed to the retrofit segment where customers are identified on a case-by-case basis (Ardani *et al.*, 2018).

With an estimated 1 million new U.S. homes constructed annually, this market offers a significant opportunity to expand solar and storage markets (Ardani *et al.*, 2018). Some homebuilders are starting to provide solar as a standard offering, led by California, where this is required (Solar Power World, 2018). The focus of this paper is on the opportunity for homebuilders to provide solar and storage as a standard offering in all new homes. This is a more nascent market, but it is emerging; the Mandalay Homes community in Arizona is one example. It is unclear how solar and storage impacts the home construction process, what barriers it faces, and what lessons have been learned thus far. Further, it is unclear how installation costs compare to retrofits and what costs might look like when new construction markets scale.

There is potential for considerable cost savings for solar plus storage in the new construction market, yet limited experience. To identify cost reduction pathways, we complete a case study analysis of Mandalay Homes' new solar and storage community in Arizona. We rely on interviews and archival research to describe how solar and storage systems can be incorporated as a standard offering in new residential communities. We then model existing and potential 2030 solar and storage costs, employing the National Renewable Energy Laboratory's (NREL's) bottom-up cost model. This modeling was vetted by 12 interviews conducted with new homebuilders, solar contractors, and other subject matter experts. These interviewees also provided key insights regarding pathways to expand solar and storage penetration in new homes, outside modeled cost savings.

2 New Construction Market, Cost, and Process

Installing solar and storage at the time of new construction has its own unique market considerations, installation costs, and related construction processes. Here, we survey the scale of the current market opportunity, existing new construction installation costs (broken down by hardware and soft costs), and document how solar and storage equipment is incorporated into the new home construction process.

2.1 New Construction Solar and Storage Market Opportunity

Ardani et al. (2018) estimate that 0.96 million new homes are expected to be constructed each year between 2017 and 2030. This represents a significant opportunity to deploy solar-plus-storage systems nationwide. This opportunity is not equally distributed across the United States; Texas, California, and Florida are the leading market opportunities for new construction, as shown in Figure 1.

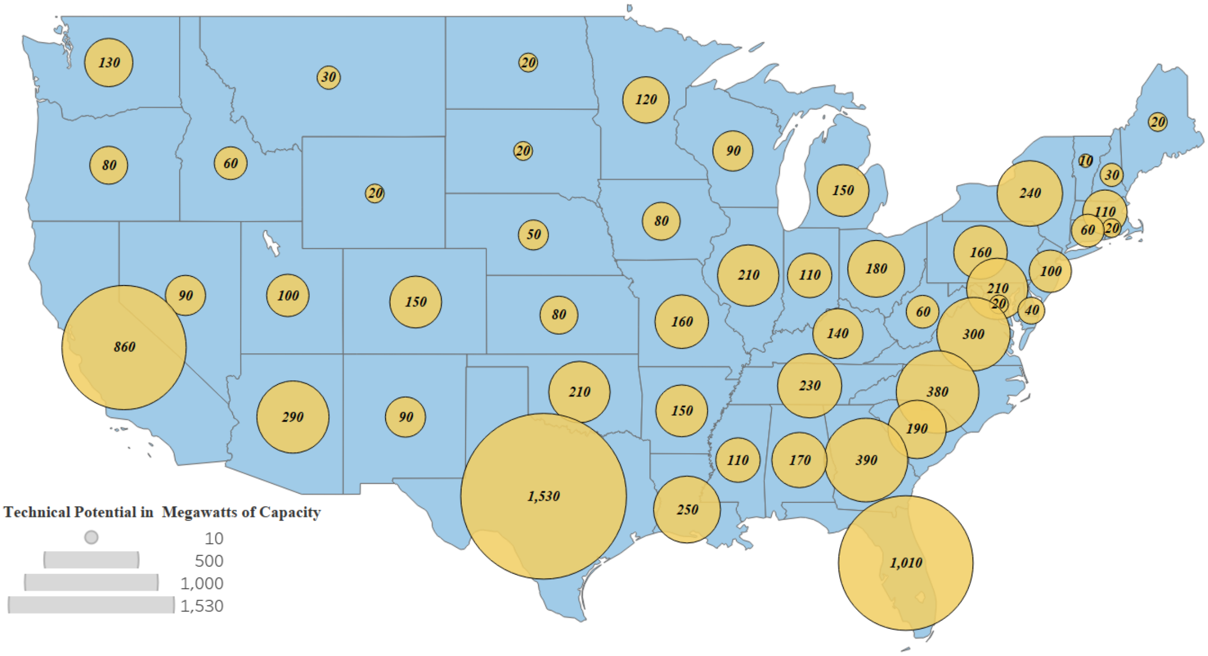

Figure 1. Projected annual average technical potential for residential rooftop PV at the time of new construction between 2017 and 2030

Adapted from (Ardani *et al.*, 2018)

At present, solar and storage is rarely offered as the standard product or primary offering within a new home community. Instead, solar-plus-storage systems may (or may not) be offered by homebuilders as an electable option for the prospective buyer. The market is evolving, as at least one homebuilder—Mandalay Homes—has started to voluntarily offer solar and storage as a standard product. In 2017, Mandalay Homes collaborated with sonnen to introduce an innovative electricity grid design to build a solar-plus-storage system on 2,900 homes in Prescott Valley, Arizona (Sonnen, 2017).

It is possible that homebuilders will increasingly offer solar and solar-plus-storage systems voluntarily or be mandated to do so. For example, California already requires all new single-family and certain low-rise multifamily homes to incorporate solar, but more recently, the state's approved 2022 Energy Code specified that developers will be required to install solar and storage systems for certain commercial and high-rise multifamily buildings beginning in 2023 (Solar Power World, 2018, 2021; California Energy Commission, 2021; PV Magazine, 2021).[1]

It is possible that similar policy mandates could apply to all residential buildings in the future, which could expand future solar and storage markets. Moreover, there are a variety of other factors that could incentivize prospective homebuyers to pursue solar and storage, such as resilience to power outages caused by natural disasters. These opportunities for the new construction market segment have not been clearly defined in the literature, nor considered in relation to how they might support broader market adoption, especially in the event that installation costs decline.

2.2 New Construction Process, Timeline, and Solar and Storage

Regardless of why solar and storage equipment is included at the time of new construction, the installation must be embedded within the building process and timeline. In 2020, the average length of time to construct a new single-family residential home in the United States, from authorization to completion, was about eight months (US Census, 2021). This process unfolds over a series of eight steps, from permitting to close of escrow (see Table 1).

Table 1. Residential New Construction Process

Step	Definition
Permitting	The homebuilder submits a permit application to the local authority having jurisdiction (AHJ) to receive construction approval.
Framing	The homebuilder conducts grading and rough plumbing and frames the home, including concrete cable, roof trusses, and other rough framing elements.
Utility Rough	The homebuilder completes rough electrical elements, including wiring and HVAC, while also completing roofing and some plumbing.
Energy Efficiency	The homebuilder installs all necessary energy efficiency elements, such as insulation.
Drywall and Interior	The homebuilder completes drywall and interior fixtures such as drywall stock, handing, and interior painting.
Utility Trim	The homebuilder completes plumbing and electrical trims while hard surface flooring and other interior elements are completed. Meanwhile, the installer arranges an energy inspection.
Finishing	The homebuilder completes the surroundings, fencing, drywall, and landscape elements.
Close of Escrow and Commissioning	After the home and final inspections are complete, the home is ready for closing with the homeowner. At this point, the solar and storage system is commissioned, typically after the homeowner has occupied the home.

It is unclear what, if any, impacts solar and storage systems might have on new home construction processes. The homebuilding process involves multiple steps and approvals, and incorporating solar and storage into that process requires coordination between the solar and storage contractor and the other impacted trades, such as roofers and plumbers. This coordination

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[1] Similarly, New York City's building code also requires certain buildings install solar (City of New York, 2019).

is likely essential to ensure the home construction adheres to the established completion schedule. If solar and storage projects delay the overall home construction timeline and also come with a higher cost for homeowners, it may make homebuilders reluctant to offer these products to their prospective customers. This analysis addresses this fundamental gap in the literature through a case study of the new solar and storage community constructed by Mandalay Homes.

2.3 Solar and Storage Costs

The cost of solar and storage is likely to be a barrier to widespread adoption, given that these systems currently cost more than standalone solar systems and the return on investment is longer in most markets (Feldman *et al.*, 2021). Existing research, which is predominately focused on retrofit solar and storage markets, suggests that costs are declining. For example, Feldman *et al.* (2021) estimated that retrofit 7-kW residential solar and Alternating Current (AC) coupled storage systems (3-kW/6-kWh to 5-kW/20-kWh systems) cost $28,371–$37,909 in 2020, which is significantly higher than installing solar alone. Though higher, these costs have been declining, by 11%–25% overall from 2016–2020 (Feldman et al., 2021).

System costs fall into two general categories: hardware and soft costs. Hardware costs include the costs of the inverter, modules, and battery pack, whereas soft costs include permitting, inspection, and interconnection (PII), customer acquisition, quality control, labor, overhead, and other nonhardware components. Both hard and soft cost categories have been declining, but not uniformly. For example, between 2016 and 2020, over 80% of the total cost reduction in residential solar and storage systems is attributed to hardware (both modules and battery packs)[2] (Feldman et al., 2021). The remainder of the cost reduction is attributed to soft costs, such as labor and customer acquisition (Feldman et al., 2021).

There have been several efforts to model future solar and storage system costs. These analyses typically evaluate residential solar and storage costs separately from each other. Depending on the scenario, the NREL Annual Technology Baseline (ATB) indicates that residential solar PV system costs may decline from $2.71/Wdc in 2020 to $0.78–$2.26/Wdc in 2030 (NREL, 2021b). Not all models suggest PV system costs will decline so precipitously. For instance, Wood Mackenzie estimates that PV system costs may decline to $2.31–$2.59/Wdc by 2025 (Wood Mackenzie, 2020), as compared to an estimated cost decline to $1.75–$2.48/Wdc in the ATB in 2025.

Meanwhile, residential standalone storage system costs are also projected to decline through 2030, but at varying rates. For residential energy storage costs, NREL's ATB estimated that battery storage costs will decline from $331/kWh in 2020 to between $145/kWh and $253/kWh in 2030, depending on the scenario. Bloomber New Energy Finance (BNEF) (2019) also projected that battery storage costs will fall within NREL's estimated range (Augustine and Blair, 2021). Though these cost estimates are illustrative of what might happen in the new construction market, they are not directly applicable to this segment. This study builds on this

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[2] The total PV module costs decreased even though the PV size in the benchmark model increased from 5.6 kW in 2016 to 7 kW in 2020. Assuming the same PV size, the price reduction from the PV module would have a higher contribution.

literature to first develop a 2020 cost benchmark for solar and storage at the time of new construction, and then to evaluate how cost reduction opportunities might be realized relative to this market through 2030.

3 Methodology

To explore solar and storage opportunities within new construction, we used a two-pronged methodology. First, we conducted a qualitative case study analysis of solar and storage systems installed at the Mandalay Homes community. This analysis sheds light on how solar and storage can be incorporated into the new home construction process and what lessons can be gathered for similar projects in the future. We supplemented these case study findings with qualitative interviews from a wide variety of subject matter experts to gain further insights beyond those specific to Mandalay. We also employed a quantitative model to estimate 2020 and 2030 installation costs for solar and storage at the time of new construction.[3] These modeled results were then vetted by our interviewees and used to elucidate opportunities to reduce installation costs and further expand new construction markets through 2030. Here, we summarize each process in detail.

3.1 Mandalay Case Study

To complete the case study, NREL reviewed existing literature and conducted interviews with six representatives from three organizations, including the homebuilder, solar contractor, and storage equipment provider. Interviewees were asked to describe their role in the construction process, lessons learned, and what opportunities exist to expand the new construction solar and storage market. In addition to this interview data, we also gathered information on 150 homes completed in the community. These data included start and stop dates for each step in the home construction process, including when solar and energy storage installation occurred. The data were not always complete, so we excluded missing data and outliers for each step.[4] We used these data to investigate the solar and energy storage installation process in relation to the entire new construction process.

3.2 National Market Opportunities and Barriers

To supplement findings from the Mandalay case study, and to inform our cost reduction modeling, we conducted qualitative interviews with representatives from 12 organizations that included homebuilders, solar and storage contractors, equipment providers, and trade associations. These interviews were semi-structured, with each stakeholder being asked five key questions:

- What are the key challenges with implementing solar and energy storage in new construction?
- What is your perspective on the current cost stack by category?
- What are the best opportunities to achieve cost reductions by 2030?
- What are the top barriers to achieving those reductions?
- What other factors might result in more solar and storage deployment beyond cost reductions?

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[3] 2020 was used as the baseline for this project, given it was the most recent year for which cost data was available at the time of analysis.

[4] On average, each step has 140 inputs.

Most subject matter experts were interviewed twice over the course of this project. The first round of interviews was used to inform the development of our installation cost models (presented in Section 5). The second round of interviews was used to vet the models we produced and identify barriers and pathways to achieving the cost reductions articulated (presented in Sections 5 and 6).

3.3 2020 New Construction Solar and Storage Baseline

Leveraging the perspectives from stakeholders, we generated two cost models. First, we developed a new Q1 2020 cost benchmark for a new construction, residential solar and storage installation. This benchmark was generated using the same bottom-up accounting framework used to develop the aforementioned 2020 retrofit solar and storage benchmark (Feldman et al. 2021).

This model has been in use since 2010 and accounts for all PV and energy storage costs by category, including associated hardware and soft costs (Ardani *et al.*, 2012, 2018; Goodrich *et al.*, 2012).[5] It attempts to estimate all direct and indirect costs associated with the installation of a PV and storage system. The cost segments include hardware costs (i.e., the module and inverter) and hardware balance of system (BOS) costs like electrical and racking/attachments. The model also accounts for soft costs such as supply chain, installation labor, PII, and customer acquisition.

Table 2 presents the 2020 Q1 NREL benchmark on a retrofitted, residential solar-plus-storage system, obtained using the bottom-up cost model.[6]

Table 2. Residential PV-Plus-Storage 2020 System Costs, Inputs, and Assumptions for AC-Coupled Systems

Category	2020 Solar and Storage Retrofit Benchmark	Description
PV System Size	7 kW	Residential rooftop systems
Battery System Size	3 kW/6 kWh storage	Lithium-ion battery, 2 hour
PV Module Efficiency	19.5%	Monocrystalline silicon modules
PV Inverter Price	$0.25/Wdc	Ex-factory gate (first buyer) prices, tier 1 inverters
PV Module Price	$0.41/Wdc	Monocrystalline silicon modules; ex-factory gate (first buyer) prices, tier 1 inverters
Lithium-Ion Battery	$253/kWh	Battery pack only
Battery-Based Inverter Cost	$174/kWh	6-kW, 48V bidirectional inverter
Structural BOS	$589	Includes flashing for roof penetrations and all rails and clamps

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[5] The modeled price does not take any tax or financial incentives into account.

[6] For a detailed description of all cost categories, see: (Feldman *et al.*, 2021; Ramasamy *et al.*, 2021).

Category	2020 Solar and Storage Retrofit Benchmark	Description
Electrical BOS	$2,755	90% of the combined BOS costs for PV and battery standalone systems
Supply Chain	$2,025	A certain percentage of costs and fees associated with shipping, historical inventory, material procurement, and other supply chain activities
Sales Tax	$704	National average: 5.1% Sales tax on the equipment
Installation Labor (Burdened) and Equipment	$2,252	90% of the combined BOS costs for PV and battery standalone systems Modeled national average labor rates
PII	$1,668	Completed and submitted applications, fees, design changes, and field inspection
Overhead (General and Administrative)	$3,584	Rent, building, equipment, staff expenses not directly tied to PII, customer acquisition, or direct installation labor
Sales and Marketing (Customer Acquisition)	$5,496	Initial and final drawing plans, advertising, lead generation, sales pitch, contract negotiation, and customer interfacing
Profit (%)	$2,164	Fixed 17% margin applied to all direct costs, including hardware, installation labor, direct sales and marketing, design, installation, and permitting fees
Total	$28,371	

To create the benchmark for new construction, NREL ran a similar modeled system—as outlined in Table 2—consisting of 19.5%-efficient monocrystalline silicon modules paired with a 3-kW/6-kWh energy storage system, and reduced the solar PV size to 4 kW. This lower system size was used to more effectively match the size of PV systems currently being installed at the time of new construction. Then, NREL applied the same new construction cost assumptions as identified for solar in our solar and storage case (Feldman *et al.*, 2021). These costs were then vetted and updated based on feedback from interviewees.

3.4 2030 Cost Reduction Modeling

Starting with the newly modeled Q1 2020 baseline, three cost reduction scenarios were generated from the literature and stakeholder feedback. These three scenarios attempt to showcase a variety of hardware and soft cost reduction opportunities along with market innovations through 2030 (Ardani *et al.*, 2018; Augustine and Blair, 2021; NREL, 2021b).

1. **Conservative Scenario**: Under this scenario, we assume that technology improves but stays largely similar to what is available on the market today, that solar and storage remains an electable but nonstandard option in new homes, and that the size of PV systems only increases somewhat relative to 2020.

2. **Moderate Scenario**: Under this scenario, we assume that technology and installation practices become more efficient, driving significant reductions in costs; that PV system size increases significantly from 2020 due to increased electrification; and that solar and storage remains an electable but nonstandard option in new homes.

3. **Advanced Scenario**: Under this scenario, we assume that there are transformative changes to the technology and installation practices, allowing for significantly lower-cost solar and storage systems; that we retain the same larger PV system size to account for growing electrification; and that homebuilders incorporate solar and storage as a standard product.

4 Case Study: Solar and Storage Deployment at the Mandalay Community

This case study is not meant to be an exhaustive accounting of the genesis of the Mandalay Homes community. Rather, the intent here is to target our analysis to two fundamental questions: (1) How is solar and storage incorporated into the new construction process? and (2) What lessons learned could be applied to other projects?[7]

Before addressing those two questions, it is important to provide context on the project. Mandalay Homes is headquartered in the Southwest and specializes in the construction of high-performance and energy-efficient homes (O'Shaughnessy *et al.*, 2022a). In 2017, Mandalay Homes partnered with sonnen to introduce a new, 2,900-home community near Prescott, Arizona, that would include solar and battery storage systems as a standard offering (Sonnen, 2017). Each of the homes is equipped with a PV system ranging from 2.48–4.5 kW and a 5-kW/10-kWh battery. Home energy costs are estimated between $30 and $40, while comparably sized homes usually pay $170–$180 per month (USGBC, 2021).

4.1 Solar and Storage and the New Home Construction Process

We begin by illustrating the complete sequence of Mandalay Homes construction steps in Figure 2, based on the median durations for each stage for the 150 homes included in our analysis. It should be noted that some key activities, especially activities between framing and close of escrow, may take place concurrently or in a slightly different order.

Even so, the solar and storage activities are incorporated into the process as outlined below. First, solar and storage projects must be permitted; this activity can happen concurrently with the new home permitting process or after. Once permitted, the solar and storage system can be rough wired and the roof prepped for the panels during the utility rough stage of the process. Then, the solar and storage system elements are installed separately, with solar getting installed first, followed by energy storage. Solar is frequently installed during the trim stage, when all other roof features and painting are complete. Storage follows thereafter, while the landscaping activities are finalized. Finally, the systems are typically commissioned after Close of Escrow (COE), the homeowner has entered the house, and set up their utility service. Variation in actual occupancy timelines account for the significant timeline skew.

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[7] For a deeper analysis relating to the performance of these solar and storage systems, see O'Shaughnessy et al. (2022a).

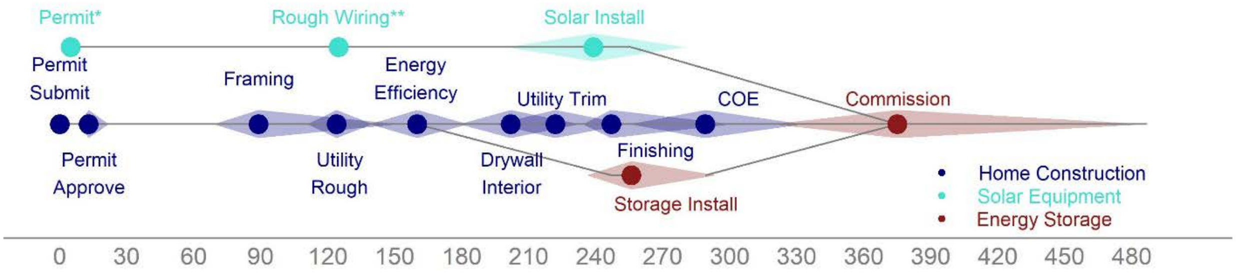

Figure 2. Mandalay Homes cumulative duration (days) based on stage median durations

*Solar and storage permitting can occur in parallel or can be combined with the new home permit. In this case, the permits were submitted separately, and data was not available on permit submission times.

**Rough wiring of the system occurs during the utility rough stage of the new construction process. NREL was not able to collect data on the duration of this step, but multiple houses can be rough wired in one day (if ready).

4.2 Solar and Storage Impacts and Lessons Learned

As noted, incorporating solar and storage into new home construction adds a layer of complexity to the building process. Here, we summarize the key lessons learned, as gathered from stakeholders involved in the construction process.

Permitting- and inspection-related issues were commonly referenced across stakeholders. These issues stemmed from variation in the enforcement of codes by local governments and local officials' unfamiliarity with the storage technology being employed. Local governments often enforce different fire, electrical, and structural requirements in their city code. This variation can influence what communities require for a safe, code-compliant solar and storage installation. Understanding these code variations can take time from the contractor, and can take even more time in situations where local governments are less familiar with the technology, which occurred in this case. Here, interviewees noted that it took time to educate local government personnel on the solar and storage equipment used. Interviewees suggested that this education effort took several meetings and ongoing dialogue between the local officials, the homebuilder, and equipment providers. Interviewees asserted that once local officials had collected information on the systems in question and became more comfortable with permitting and inspecting them, the processes became more efficient. Although interviewees noted that permitting and inspection delays occurred, they also noted that it did not influence the overall new construction timeline.

Although incorporating solar and storage into the new construction process did not delay construction, it still required additional communication and coordination between trades. Interviewees reported that communication was critical to ensure that solar and storage was installed efficiently, thereby keeping construction on schedule. Lack of communication in particular can result in "dry runs," where the solar contractor travels to the site and there are no homes that are ready for the contractor. Dry runs are a significant cost to the solar contractor, given that truck rolls (or travel) to a site that result in idle staff are very costly. Dry runs can still occur even if the contractor is told by the homebuilder the day before that a particular home is planned to be ready. In most situations, dry run costs must be absorbed by the contractor, and then potentially by homeowners. In this case, interviewees noted that the solar contractor had the opportunity to charge the homebuilder for these dry runs, but that model is not common nationwide. Trade coordination must continue even after installation, to also include interactions between the homebuilder and the utility, to ensure the systems can be interconnected to the grid after installation.

Although these coordination issues increase as construction scales, so too do economies of scale. Interviewees confirmed that the smaller sizes of the PV systems associated with these energy-efficient homes, along with their proximity to each other, allowed the contractors to install more systems per day than would otherwise be possible. The actual rate of improved efficiency varies depending on the unique characteristics of the home's design and what other homes are ready for various solar and storage installation processes. Interviewees noted that in ideal settings, they were able to complete 2–3 installs per day.[8] Interviewees confirmed that these economies of scale can reduce installation costs and thereby improve the value proposition of the systems.

However, these economies of scale do not always appear. In some cases, interviewees noted that homebuilders will slow construction processes, reducing the opportunities to complete more than one installation a day, or only one project will be ready and must be completed on its own. In addition, the individual characteristics of the installation can influence whether it is possible to do other installs, given that even new homes and related solar and storage systems are not always the same size or configuration.

Pathways to further reduce costs, via economies of scale or otherwise, may be essential going forward. Interviewees confirmed that solar and storage systems are costly, and some prospective homeowners may be reluctant to adopt them given long return-on-investment timelines. Interviewees noted the need to track the performance of these systems and to determine mechanisms to monetize potential value streams, such as resilience, to further incentivize widespread adoption.

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[8] Importantly, this does not reflect installing 2–3 solar and storage systems completely in one day; rather, this refers to 2–3 installations of solar or storage, or some combination of that equipment (or rough wiring) at various construction sites.

5 Modeled New Home Solar and Storage Costs

As the case study results suggest, finding pathways to reduce solar and storage costs may be critical to expanding the market. Assessing cost reduction opportunities requires first understanding what the current costs are, and then what reduction pathways may be possible. Here, we present our modeled costs for 2020 and 2030, along with the opportunities and barriers associated with achieving the modeled costs.

5.1 2020 Cost Benchmark Results

Table 3 shows the new construction solar and storge system cost for AC-coupled systems at $22,105, which is $6,266 (22%) less than the price of the retrofitted solar and storage system (Table 3).[9] The price reductions are influenced by the size of the PV system along with assumed savings for PII and customer acquisition reflected in the new construction model for standalone solar (Feldman et al. 2021). These lower soft costs were based on Feldman et al.'s (2021) assumptions that solar installed at the time of new construction comes with an estimated 25% savings in soft costs (Feldman *et al.*, 2021). The expectation is that PII of many systems at once comes with economies of scale that can reduce truck rolls to and from locations or permitting offices. In addition, customer acquisition costs are expected to decline in comparison to the retrofit market, given that engaging with homebuilders may require less engagement with individual customers.

Table 3. Residential Solar and Storage 2020 Retrofit vs. New Construction System Costs and Assumptions for AC-Coupled Systems

Category	2020 Retrofit Case	2020 New Construction Benchmark	Assumptions, From Retrofit to New Construction
PV System Size	7 kW	4 kW	Current residential PV sizes are smaller
Battery System Size	3 kW/6 kWh storage	3 kW/6 kWh storage	No changes
PV Module Efficiency	19.5%	19.5 %	No changes
PV Inverter Price	$0.25/Wdc	$0.25/Wdc	No changes
PV Module Price	$0.41/Wdc	$0.41/Wdc	No changes
Lithium-Ion Battery	$253/kWh	$253/kWh	No changes
Battery-Based Inverter Cost	$174/kWh	$174/kWh	No changes
Structural BOS	$589	$595	Slight change due to revised model construction and inflation

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[9] Modeled Direct Current (DC) coupled system costs are included in the Appendix. This analysis also does not consider any homebuilder markups. This could result in higher costs to the home purchaser.

Category	2020 Retrofit Case	2020 New Construction Benchmark	Assumptions, From Retrofit to New Construction
Electrical BOS	$2,755	$2,538	Change due to revised model construction and inflation, and revised PV size
Supply Chain	$2,025	$1,359	Change due to revised model construction and inflation, and revised PV size
Sales Tax	$704	$514	No change in 5% tax rate; cost declines given total installation cost declined
Installation Labor (Burdened) and Equipment	$2,252	$1,996	Slight change due to revised model construction and inflation, and revised PV size
PII	$1,668	$1,273	PII reduced by 25% (Feldman *et al.*, 2021)
Overhead (General and Administrative)	$3,584	$3,637	Slight change due to revised model construction and inflation
Sales and Marketing (Customer Acquisition)	$ 5,496	$3,221	Sales and marketing costs reduced by 25% (Feldman *et al.*, 2021)
Profit (%)	$2,164	$1,758	No change in profit margin %; cost reduced due to revised PV size
Total	$28,371	$22,105	Reduced by 22%

5.2 2030 Cost Reduction Assumptions

From the 2020 baseline, we developed three new cost reduction scenarios through 2030 to represent conservative, moderate, and advanced cost reduction opportunities. The key cost reduction assumptions and results are presented in Table 4.

First, we increased solar PV size and kept battery sizes consistent between now and 2030. Stakeholders disagreed on whether it is more likely for PV system sizes to increase, stay the same, or decrease as homes become more efficient and module efficiency improves. The counterbalancing trend, as outlined by stakeholders, is the push for greater home electrification that would increase load and could result in larger systems. Based on conversations with stakeholders, this study assumes that increased electrification will result in larger PV systems being installed by 2030, even as homes become more efficient.[10]

Second, the hardware cost reductions for solar (module, inverter, and efficiency) and the battery (pack and inverter), as well as the structural and electrical BOS cost estimates, were initially based on NREL's ATB (NREL, 2021a). We then vetted and updated these cost estimates after stakeholder feedback. The opportunities and barriers to achieving these cost targets are summarized later in this section.

Third, stakeholder feedback was essential for our soft cost estimates and associated assumptions, also outlined in Table 4. These opportunities are detailed in full later in this section.

Table 4. Residential Solar and Storage 2030 System Cost Scenarios, Assumptions, and Results for AC-Coupled Systems

Category	Benchmark	Conservative	Moderate	Advanced	Key Assumptions
PV System Size	4 kW	5 kW	7 kW	7 kW	Size increases in the future
Battery System Size	3 kW/6 kWh	3 kW/6 kWh	3 kW/6 kWh	3 kW/6 kWh	Size remains the same due to modeling constraints, but storage sizes are likely to increase
PV Module Efficiency	19.5%	21.5%	22.5%	25%	Efficiency gains are expected, but improvement rates are uncertain
PV Inverter Price	$0.25/Wdc	$0.15/Wdc	$0.10/Wdc	$0.05/Wdc	Prices are expected to decline, but decrease rates are uncertain
PV Module Price	$0.41/Wdc	$0.32/Wdc	$0.19/Wdc	$0.17/Wdc	Prices are expected to decline, but decrease rates are uncertain
Lithium-Ion Battery	$253/kWh	$193/kWh	$83/kWh	$119/kWh	Prices are expected to decline, but decrease rates are uncertain
Battery-Based Inverter Cost	$174/kWh	$133/kWh	$117/kWh	$82/kWh	Prices are expected to decline, but decrease rates are uncertain
Structural BOS	$595	$540	$397	$357	Costs may decline as fewer components need to be installed, but decrease rates are uncertain

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[10] NREL's modeling limitations relative to the 2020 benchmark made it difficult to model larger batteries. Largely PV systems could justify larger batteries to support grid activities and backup power needs. Our modeled system would not provide significant backup power, which may be a key priority of homeowners that would also increase costs.

Category	Benchmark	Conservative	Moderate	Advanced	Key Assumptions
Electrical BOS	$2,538	$2,262	$2,091	$1,712	Costs may decline as fewer components need to be installed, but decrease rates are uncertain
Supply Chain[11]	$1,359	$ 1,585	$1,735	$1,735	Supply chain costs increase due to increased PV size, but are countered by some modeled cost savings opportunities
Sales Tax (%)	$514 (5%)	$441 (5%)	$361 (5%)	$299 (5%)	Taxes remain at 5% fixed rates. Costs decline based on overall project costs declining
Installation Labor (Burdened) and Equipment	$1,996	$2,017	$2,067	$2,047	Labor costs remain largely flat, as wages may increase even if labor hours decline
PII	$1,273	$1,179	$1,185	$1,061	Streamlined PII processes and requirements may result in lower costs, but application fees are expected to remain constant
Overhead (General and Admin)	$3,637	$3,240	$3,268	$2,747	Overhead costs are assumed to decline as solar and storage becomes a more standard product and business structures evolve at varying rates
Sales and Marketing (Customer Acquisition)	$3,221	$2,789	$2,818	$2,251	Sales and marketing costs are expected to decline as solar and storage is offered more frequently or as a standard product in new homes
Profit (%)	$1,758 (17%)	$1,886 (21%)	$1,688 (22%)	$1,688 (25%)	Though profit margins increase as a percentage of overall costs, they decline slightly in the moderate and advanced cases due to expected competition and economies of scale
Total	$22,105	$20,254	$18,848	$16,645	

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[11] This study assumes supply chain cost per kW PV stays the same from the benchmark to the conservative scenario. We applied a 15% fixed reduction on the supply chain segment for the moderate and advanced scenarios, relative to a modeled 7-kW system and not the 4-kW benchmark. However, the 7-kW system employs the same assumptions as that of the base case. We used the same price projection approach to estimate the profit segment, but applied a 22% fixed reduction for moderate and advanced scenarios.

Figure 3 shows these cost projections for the AC-coupled system in each scenario. Here, it is clearer that hardware costs account for the majority of cost reductions, followed by soft costs.[12] Overall system costs are expected to be reduced by 13%–25% as compared to the benchmark case, depending on the scenario.[13]

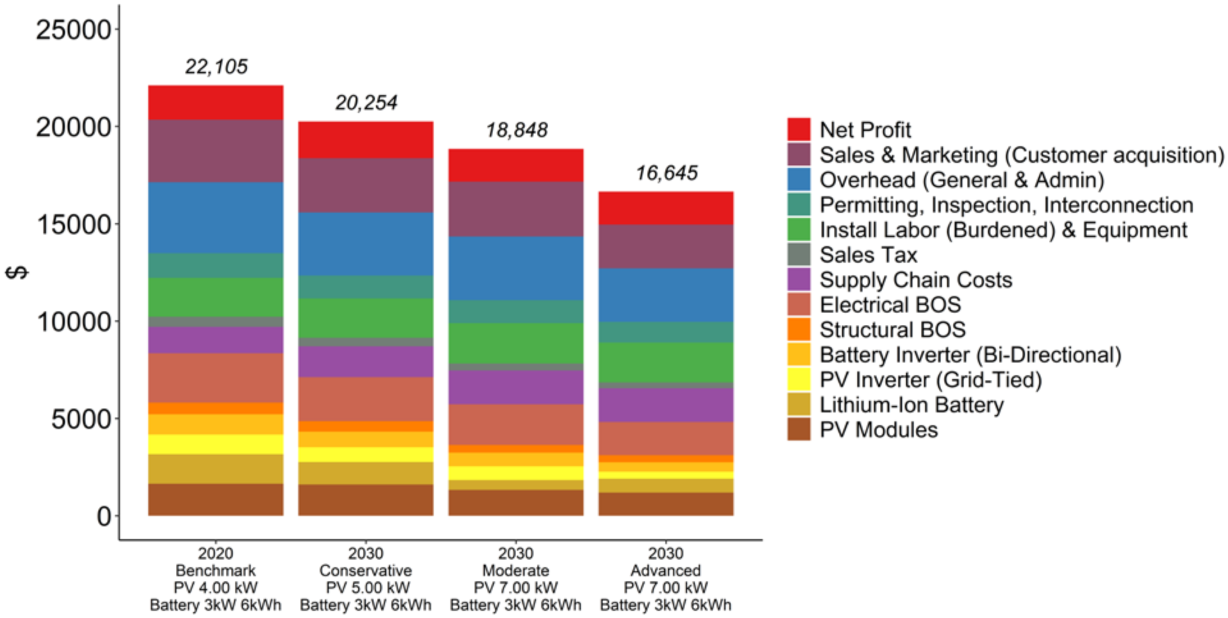

Figure 3. Comparison of current and 2030 residential PV plus AC-coupled storage costs

Table 5 shows that PV and battery materials, such as the module, battery pack, and inverter segments, contributed between 45% and 61% of the total estimated cost reduction, depending on the scenario. Thereafter, two soft cost categories, customer acquisition and overhead, account for ~11%–23% of the cost reduction. The fourth leading cost reduction category is again associated with hardware: electrical BOS costs, which account for 14%–15% of the cost reduction.

Some costs do increase in our modeling, including supply chain and labor costs. Supply chain costs increase mainly due to the increasing PV size (from 4 kW in the benchmark to 7 kW in the advanced scenario).[14] On the other hand, installation labor costs show a smaller increase because this cost segment is not as sensitive to increasing PV size as the supply chain segment.[15] The remaining cost savings are spread across a variety of hardware and soft cost categories (see Table 5).

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[12] Modeled costs for a DC system are provided in the Appendix.

[13] None of these scenarios model profit to the homebuilder. Where solar is incorporated into the sale of the home or added as an option, the homebuilder may apply their own profit margin to the added product. That margin would then be applied atop the costs outlined here.

[14] Although supply chain costs increase, some of the increased cost is counteracted by cost savings in this category relating to reducing the quantity of equipment and parts that are required.

[15] Profit goes up in the conservative case, given the increase in PV size. Profit declines in later scenarios, given expected increases in competition and economies of scale requiring lower profit margins on individual projects.

Table 5. Cost Reduction Percentage Contribution by Category

Segment	2030 Conservative	2030 Moderate	2030 Advanced
PV and Battery Hardware	48.52%	60.67%	45.16%
Sales and Marketing (Customer Acquisition)	23.32%	12.36%	17.76%
Overhead (General and Admin)	21.41%	11.33%	16.30%
Electrical BOS	14.89%	13.73%	15.12%
Structural BOS	2.99%	6.08%	4.35%
Sales Tax	3.97%	4.71%	3.95%
PII	5.10%	2.70%	3.88%
Net Profit	-6.91%	2.14%	1.28%
Installation Labor (Burdened) and Equipment	-1.10%	-2.19%	-0.93%
Supply Chain Costs	-12.19%	-11.53%	-6.88%
Total Reduction, $ and % Compared With Benchmark	**$1,851 (8.4%)**	**$3,257 (14.7%)**	**$5,460 (24.7%)**

5.3 Key Cost Savings Opportunities and Related Barriers

Despite the opportunity for immense savings, stakeholder feedback generated a variety of considerations or barriers related to achieving these aggressive cost targets. Moreover, stakeholders confirmed that it is possible that some costs could increase, as opposed to decreasing (i.e., labor costs). Here, we summarize the potential opportunities and barriers associated with leading cost reduction categories.

5.3.1 Hardware

To achieve the cost reduction targets referenced in Section 5.2, battery, module, inverter, and other electrical BOS costs will need to decline. The expectation in our model is that battery technology will experience a similar cost reduction trend to that of solar, for both the battery (24%–67% reduction) and the associated inverter (-24%–53%). This is paired with expected cost reductions (per kW) for the PV module (-22%–59%) and the associated inverter (-40%–80%). Though modules and inverters have already seen significant cost reductions, interviewees confirmed that additional savings could result from further manufacturing automation and continued technology innovations, especially for the battery (NREL, 2021a).

The significant electrical BOS cost savings are largely associated with improvements in battery and inverter technology that allow for running less electrical wire, in less complex configurations, and through less conduit and fewer boxes. For example, manufacturers have developed backup switch meter socket adapters and other technology innovations for solar and storage systems that can reportedly reduce equipment and installation times (Sonnen, 2020; Tesla, 2021). One company also offers a $500 credit to customers where these products can be used (Tesla, 2021). Interviewees suggested that as these and other products are brought to market, they could further streamline electrical BOS costs. At the same time, interviewees asserted that increased standardization of PV and battery storage system design and installation packages could further reduce BOS and other hardware costs, even in the absence of these new technologies.

Though these cost reductions are possible, interviewees further noted that there are a variety of factors that could result in battery, module, inverter, and related electrical BOS hardware costs staying the same or declining at a slower rate in the future.

First, recent battery cost estimates have not shown significant cost reductions, suggesting that these technologies have not yet seen the same pace of cost reduction as solar has over the past decade. For example, behind-the-meter energy storage prices remained flat from 2019–2021 due to the lack of supply and increased upstream prices (Wood Mackenzie, 2021b). At the same time, some costs may increase given higher demand for raw materials and/or supply chain and material shortages. In addition, public health and safety code requirements for storage, notably fire safety requirements, are evolving. This evolution may influence how batteries are installed, which could increase costs.

Second, PV systems may face similar challenges in relation to supply chain costs and technology innovation. For example, PV module prices have risen 6% in Q1 2021 due to the increasing shipping costs of sourcing materials (Feldman *et al.*, 2021). Wood Mackenzie (2021a) also indicated that residential system prices will increase year-over-year in 2021 due to increasing labor costs and pricing strategies. For this and other reasons, it is unclear whether solar modules and inverter costs will continue to decline, especially as costs have begun to plateau or increase in recent years.

Third, the technology innovation and system design standardization opportunities come with their own potential barriers. First, new technologies, such as meter socket adapters, require approval by regulatory bodies and code officials for use. The development, commercialization, and regulatory approval of these technologies can take time, thereby reducing the potential impact these innovations could have by 2030. In addition, expanding the standardization of PV and ESS designs and installation packages might impact individual homeowners' ability to customize the roof layout and related design characteristics. The benefits of standardizing PV and storage layouts will have to be balanced with purchaser preferences and/or the homebuilder's existing practices.

5.3.2 Customer Acquisition

Interviewees confirmed that customer acquisition costs are lower in the context of new construction than in retrofits (Feldman *et al.*, 2021), given that the solar and storage contractor can focus on homebuilders or new subdivisions instead of always focusing on individual homeowners. Interviewees also suggested that these cost savings could accelerate in the future, especially as solar and storage at the time of new construction gains market share.

Interviewees further noted that the economic performance of the system and its return on investment to the homeowner continues to be one of the most significant factors in a homeowner's decision. Reductions in the total installed cost will result in a faster return on investment, while other market developments, such as rate design changes (discussed in Section 6), can further improve the value of the system to the homeowner. Interviewees asserted that these developments could reduce the resources needed to make initial sales to prospective customers, given that the product may be more attractive to the customer.

In addition, interviewees noted that solar and storage systems could be offered more frequently as a standard product than they are today. If homebuilders were to take a similar approach to that of Mandalay, then solar and storage contractors would have significantly lower customer acquisition costs, given that the costs of acquisition could be spent identifying the initial homebuilder rather than each purchaser.

Interviewees also noted some barriers to achieving these lower acquisition costs. Currently, adding storage comes at a significant cost, and the economic case is not always clear in all specific markets. With housing costs increasing, homebuilders and homeowners may be hesitant to add products that are, or are perceived as, higher cost, making customer acquisition more challenging. Interviewees suggested that these factors could temper the opportunities to reduce these costs. At the same time, interviewees noted that homebuilders may be reticent to provide these as standard products, even when economics are favorable, given concerns regarding performance uncertainty of the solar and storage products. Homebuilders may be concerned that the homeowner expectations of these third-party products will not be met, resulting in reputational risk or possible legal action to the homebuilder. These risks might be balanced by the revenue generated from including these products in the home sale, but this model is not always used, and the revenue generated may not be sufficient for all homebuilders to accept the risk.

5.3.3 Overhead

Overhead cost savings are associated with 11%–24% of the modeled cost reduction through 2030. The overhead category incorporates a wide variety of costs, including office space, management, and accounting, among others.

This is also a category in which excess or otherwise hidden costs elsewhere might be captured. For example, interviewees stressed that permitting solar and storage systems can require education and discussions with each local government in which the contractor operates, requiring the contractor to devote specialized electrical, fire, and structural engineer resources to participate in these meetings. These types of interactions were present in the Mandalay case. These costs are not fully covered within the PII category, which covers application fees, application creation, and submission activities in which these staff may not always be directly involved. This is especially important in the context of solar and storage, where local governments and utilities are still learning about this rapidly evolving technology. Some states, including New York and Massachusetts, have developed guidance materials to help local governments safely permit these systems (NYSERDA, 2020; Massachusetts, 2021). Interviewees suggested that as more local governments and utilities get familiar with the technology and building codes become more standardized, this could reduce some of these hidden costs in the future.

Interviewees also confirmed that economies of scale and the ability to distribute overhead costs over a wider pool of projects can result in reduced overhead costs on a per-project basis. In short, cost savings elsewhere can have significant benefits in the overhead category as well, given that adoption volume is expected to increase, especially when solar and storage are incorporated as a standard product on all new homes.

Rapidly evolving business practices within the solar and storage industry and the market more broadly could also result in lower costs. Many businesses are closing offices and selling real estate in favor of virtual and teleworking models (Davidson, 2021). This is also true in the solar and storage industry; some solar contractors have already closed or consolidated office space in favor of virtual or collocated sales with other products (i.e., electric vehicles) (Sage, 2019). These and other business practice changes may further reduce future overhead costs.

At the same time, interviewees also identified barriers to achieving these cost savings. As noted, local governments and utilities continue to have widely different PII requirements for solar, even though solar has been rapidly expanding its market share for more than a decade (NREL, 2021c; O'Shaughnessy et al. 2022b). Interviewees went on to suggest that this variation in requirements is further complicated when storage is added to the solar installation. This is in part because storage equipment is not all the same, and different products have different battery chemistry, installation requirements, and enclosures that are all addressed in building codes somewhat differently. Local governments and utilities may then enforce those codes differently, requiring an immense knowledge of building codes and subsequent code-related dialogue with communities and utilities. Building up this expertise and deploying it across local governments and utilities could result in higher overhead costs. At the same time, interviewees noted that the market may continue to expand and become more competitive. This could lead to contractors seeking to expand their business, resulting in more overhead costs that need to be spread across a growing pool of projects. Therefore, overhead cost savings as modeled here are far from certain.

5.3.4 Labor

In our modeled results, installation labor costs slightly increase. Interviewees had competing perspectives on whether there is an opportunity for labor cost savings. On the one hand, interviewees confirmed that labor costs could go down if fewer modules and other equipment need to be installed on-site. This could result from technology improvements and/or off-site automation. In addition, there could be opportunities to increase standardization of designs and otherwise decrease the complexity of installation to be closer to other plug-and-play appliances. Interviewees suggested that if this occurs, it might allow for using more available labor or cross-training other trades, such as roofers, to perform the solar and roofing activities. This could potentially result in the roofers installing the PV at the same time as they would have otherwise installed the roof, thereby eliminating or significantly reducing additional solar labor time.

In contrast, some interviewees pointed out that historically, labor rates have not gone down; they have only increased. Moreover, it may be difficult to find and/or train the workforce to be able to complete solar and storage installations. This may require increases in labor rates to carry out the same work. Another challenge is that current installation processes require a minimum of three visits to the same home to complete the work (rough wire, solar, and then storage installation), as opposed to one visit to complete a retrofit. The lack of communication or staggered housing construction processes can result in more dry runs to the site or require the solar contractor to complete fewer installation activities in one day than is optimal. As noted, technology innovations could result in the need for fewer separate trips to complete the installation, but that requires new products that have not yet materialized. These factors could result in labor costs staying the same or going up through 2030. In short, the future of labor costs in this context is significantly uncertain.

6 Market Opportunities Beyond Cost Savings

Stakeholders further identified a variety of other pathways that could significantly expand solar-plus-storage markets, in parallel with or without installation cost reductions. These opportunities relate to financing, rate design, resilience programs, adoption mandates, and distributed energy resource (DER) aggregation programs. This section briefly summarizes each of these opportunities in turn.

6.1 Financing

There are a variety of opportunities to finance solar and storage systems at the time of new construction that can eliminate upfront costs, thereby encouraging more solar and storage adoption (Hancock, 2019). In fact, one study found that installing solar at the time of new construction will cost $33 less per month than a retrofit option, given the lower interest rates that can be secured for mortgages as compared to market rates (DOE 2016). There are four common financing approaches that can apply for both solar and solar and storage projects:

- Roll into home mortgage
- Separate solar and storage loan
- Separate solar and storage lease
- Separate solar and storage power purchase agreement (PPA).[16]

Each of these four options can be designed to eliminate upfront cost requirements, making adoption more attractive. This can be important given that the cost of homes is increasing and homeowners may not have excess capital to pay a price premium for these systems. The costs of the system are then recovered over time. These charges can typically be structured to be less than the total electricity bill savings of the homeowner, resulting in net savings each month.

As one example, the Federal Housing Administration (FHA), a key mortgage financier, has developed an Energy Efficient Mortgage program to encourage and assist homebuyers in making their homes as energy-efficient as possible (HUD, 2022). This program can include solar as long as it passes the FHA's "cost-effective" test (Unbound Solar, 2021). It is possible that innovations in this and other programs may be able to consider storage as part of the financing package.

Despite the benefits of these financing options, they do come with their own complexities and implementation costs for the solar and storage provider (either the homebuilder or a separate solar and storage contractor). These financing-related costs can appear within the overhead cost category. As these financing methods become more common and easier to implement, they may result in more favorable terms for homeowners. Even so, some of these financing options are not available everywhere. For example, third-party PPAs for solar are only allowed in 29 states and Washington, D.C. (DSIRE, 2021). This lack of access can itself influence market opportunities.

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[16] Some homeowners may forgo financing and instead pay for the system upfront with cash.

6.2 Rate Design

Rate design influences the compensation a solar-plus-storage customer will receive for the operation of the battery. Certain rate structures can incentivize or disincentivize the use of battery storage in tandem with solar projects. Today, net metering programs are common in the market; these programs compensate electricity for residential solar at the retail rate of electricity at any time the generation is discharged. This model, by itself, does not always incentivize storage, given there may be no incentive to charge and discharge the battery.

Hawaii is one example of a state that has instituted rate designs that incentivize the use of battery storage in tandem with a PV system (Hawaiian Electric, 2021). The Hawaiian Electric program and other similar programs institute TOU rates and demand charges that encourage the charging of batteries with solar generation during the day and discharging at peak times to reduce demand on the electrical grid. The solar and storage systems enable energy arbitrage by shaving and shifting the energy demand, thus reducing the demand charges. Therefore, rate-making can play a critical role in incentivizing battery storage, resulting in homeowners recouping their investment in batteries faster than otherwise, regardless of the underlying installation costs.

However, rate design modifications can introduce other externalities and may not encourage more solar and storage adoption in some cases. First, the implementation of TOU and demand charge programs does not guarantee more deployment. If the peak and off-peak period charges are not significantly different, coupling storage with solar may not be economically attractive. Similarly, if a homeowner's load profile (or electricity consumption) is relatively constant throughout the day, it may be difficult to benefit from discharging the battery during on-peak periods (Cook *et al.*, 2020). Second, these programs influence who installs solar and storage and who does not. For those who do adopt solar and storage, it is possible that the TOU and demand charge programs will result in higher utility bill payments than for customers who do not adopt, or vice versa (McLaren *et al.*, 2015). Even when rate design incentivizes solar and storage adoption, that deployment may not be equal among customers. In some cases, low- and moderate-income residents who do not adopt solar, may pay more for electricity as a percentage of their income than those who do install. In short, how rate programs are structured will ultimately determine whether customers will have sufficient benefit to justify the investment.

6.3 Resilience Programs and Policies

Since 1980, the frequency of significant natural disasters has increased within the United States to an annual average of seven disasters, with damages exceeding $1 billion annually. In 2020 alone, the United States had a record 22 significant natural disasters (NOAA, 2021). These events typically result in power outages that can last for days or weeks.

Given the growing frequency of natural disasters, a variety of states, localities, and utilities are considering resilience programs that can help the electrical grid recover from these and similar disruptions (DOE, 2015). As of 2018, seven states had adopted grants, loans, and financing programs to support the deployment of distributed solar and storage systems in a variety of sectors (Cook, Volpi, *et al.*, 2018).

In addition, some utilities have preemptively shut off electricity to prevent wildfires that could become significant natural disasters (New York Times, 2021b). For example, Pacific Gas &

Electricity (PG&E) in California implements Public Safety Power Shutoffs (PSPS) to mitigate wildfire risks under high winds and extreme drought conditions (PG&E, 2021a). In October 2021, PG&E implemented a PSPS affecting approximately 25,000 customers from 20 counties for a day (PG&E, 2021b). These voluntary shutoffs have further encouraged residents to consider solar and storage projects to be able to maintain electricity during these more frequent events (New York Times, 2021b).

Although these and other resilience programs can support solar and storage markets, there are constraints on the opportunity presented here. First, the value of resilience is difficult to quantify, making it hard to recoup investments, especially given that operation during outages in the residential context is uncompensated (McLaren and Gagnon, 2018). Customers may also be hesitant to pursue more resilient systems considering they often come with higher costs. For example, PV paired with more extended energy storage (up to 4-hour duration as opposed to 2-hour duration) may cost about $10k more (Feldman *et al.*, 2021).

6.4 Solar and Storage Deployment Mandates

The proliferation of policy mandates to deploy solar and storage at the time of new construction could also expand the market. As noted, California has been a leader in this area, requiring solar—and now solar and storage—in certain commercial and residential buildings (Energy Sage, 2021; AXIOS, 2021; California Energy Commission, 2021). If this or another policy was implemented to require solar and storage in a broader set of new residential building construction contexts, it would increase deployment.

Although mandates can rapidly expand the market, they come with their own considerations. First, adopting policy mandates requires policymakers to pass new legislation, which is a time-intensive and uncertain process. Given this challenge, some states and localities have also adopted less aggressive "solar-ready" programs, which require the homebuilder to consider a variety of solar-related factors in the construction of the house, such as building orientation, wiring, and equipment installation needs. Prior to California's mandate, the state originally required homes be solar-ready (Solar Power World, 2020). Some cities outside California have also required solar-ready homes, including Orlando, Florida; St. Louis, Missouri; and Tucson, Arizona. For example, Tucson requires new single and duplex residential dwelling units to include an acceptable approach for solar installation in the future for heating purposes (City of Tucson, 2008). These programs have further been expanded to consider storage, which is required in the state of California. Although these programs come with fewer costs than deployment mandates, they do not require solar and storage installations, and thus have less effect on overall deployment and related benefits.

6.5 DER Aggregation Programs

As of 2018, there were 23 utility-led DER aggregation programs being piloted or implemented across the United States (Cook *et al.*, 2018). These programs, also known as virtual power plants, control multiple DERs and dispatch them based on electrical grid market signals. The control and operation of these programs varies nationwide. In short, these programs allow DERs to provide a variety of grid services, including load shifting, frequency response, and voltage regulation, among others, while being compensated for those actions. There are additional opportunities for DERs to provide benefits to the retail and wholesale markets as well.

The proliferation of these types of programs could generate more value opportunities for solar and storage systems, thereby reducing the return-on-investment timeline and potentially encouraging more solar-plus-storage adoption. The Mandalay Homes community could operate as a virtual power plant, but currently the homes operate individually to maximize savings to each homeowner (O'Shaughnessy et al. 2022a). This is in part because a rate structure has not been designed that would incentivize the operation of the homes as a fleet. If such a program and related rates existed, it is possible that this community could not only provide benefits to the grid, but also provide more resilience to the grid (O'Shaughnessy et al. 2022a).

Although DER aggregation programs could expand solar-plus-storage deployment, these programs are just emerging, which tempers their potential impact in the shorter term. For example, a recent study notes that compensation mechanisms, DER control and orchestration, communication, performance reliability, and consumer behavior impacts, among other considerations, must be evaluated and addressed for these programs to be scaled nationwide (Cook *et al.*, 2018).

7 Conclusion

Installing solar and storage at the time of new construction can result in a significant opportunity to expand deployment, potentially at lower cost than retrofits. Even so, there are unique barriers that must be overcome to serve this market, relating to the homebuilding process and installation costs, that are not well understood in the literature.

This research addresses this gap through a case study of a recent new home community where solar and storage was installed as a standard product. In addition, we model the costs of solar and storage installed at the time of new construction and identify pathways to reduce these costs or otherwise open markets through 2030.

Our case study analysis generated three key considerations for homebuilders considering deploying solar and storage as standard products in their future communities, including:

1. Educating local permitting, inspection, and, in some cases, utility officials on solar and storage products, designs, and code-compliant building practices may be required. The need for education may decline as more local governments and utilities approve solar and storage projects.

2. Incorporating solar and storage systems into the homebuilding process can add complexity and related coordination challenges, but this does not need to result in home construction delays.

3. Deploying solar and storage at the time of new construction has significant economies of scale, which offer potential cost savings opportunities and can thus improve the value proposition of the systems.

Our results further suggest that there are four key cost reduction opportunities, relating to solar and battery hardware, customer acquisition, overhead, and potentially labor. If future contractors can maximize the cost reduction opportunities of solar and storage, costs may decline 8%–25% from the 2020 baseline by 2030, depending on the scenario. Though there are potential opportunities for future cost reduction between now and 2030, it is unclear which of these scenarios is the most likely.

Cost reductions are not the only pathway to increase solar and storage deployment at the time of new construction. Interviewees confirmed that changes in financing, rate design, resilience policies, deployment mandates, and DER aggregation could all support more market adoption than is seen today. In most cases, this would require legislative or regulatory action, which is often a slow and uncertain process.

Overall, this is an exploratory study, and future work is required to understand the applicability of the Mandalay Homes findings to future new solar plus storage housing developments. In addition, more work is necessary to assess the viability of the cost reduction pathways identified along with the effects lower costs may have on deployment. Regardless, this work suggests that solar and storage can be successfully incorporated into the new home construction process, with the potential for significantly lower costs in the future. If realized, this could result in significant solar and storage deployment through 2030 and beyond.

Appendix

Table 6. Residential PV-Plus-Storage 2030 System Cost Scenarios, Assumptions, and Results for DC-Coupled Systems

Segment	2020 Benchmark	2030 Conservative	2030 Moderate	2030 Advanced
PV Modules	$1,640	$1,600	$1,330	$1,190
Lithium-Ion Battery	$1,518	$1,160	$501	$713
PV Inverter (Grid-Tied)	$0	$0	$0	$0
Battery Inverter (Bidirectional)	$1,044	$798	$699	$491
Structural BOS	$595	$540	$397	$357
Electrical BOS	$2,860	$2,464	$2,301	$1,763
Supply Chain Costs	$1,377	$1,603	$1,750	$1,750
Sales Tax	$533	$452	$373	$302
Installation Labor (Burdened) and Equipment	$1,737	$1,757	$1,808	$1,788
PII	$1,273	$1,179	$1,185	$1,061
Overhead (General and Admin)	$3,637	$3,240	$3,268	$2,747
Sales and Marketing (Customer Acquisition)	$2,816	$2,384	$2,413	$1,846
Net Profit	$1,597	$1,682	$1,462	$1,462
Total	$20,627	$18,859	$17,488	$15,471

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